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Chapter 1 Introduction

1.1 Background and Objective

1.1.1 General remarks

The concept of preservation of groups of traditional buildings generated from the context of Protection of Cultural Relics. The trend of preservation of traditional districts in Japan can be traced back to the activities of preservation of buried cultural relics after the 2nd world war and the legislation of the Protection of Cultural Properties in 1950. As the historic value of traditional districts had been recognized, the urgent investigation on vernacular houses had been conducted by Cultural Properties Protection Committee in late 1960s. In the meantime, the activities were also promoted by the inhabitants by the name of creating community, and the various kinds of landscape controlling regulations had also been gradually introduced by municipals in different regions. Until 1975 the category of the Important Preservation Districts of Groups of Traditional Buildings (IPDGHB) had been introduced by the amendment of the Law for Protection of Cultural Properties, the system of IPDGHB was formally established. The significance of the historic value and townscape was highlighted throughout the forming of IPDGHB system.

The Important Preservation Districts for Groups of Traditional Buildings are designated according to one of three criteria:

- (1) Groups of traditional buildings that show excellent design as a whole
- (2) Groups of traditional buildings and land distribution that preserve the old state of affairs well
- (3) Groups of traditional buildings and their surrounding environment that show remarkable regional characteristics

All the important preservation districts are classified into eight categories:

- (4) Villages: mountain village, farming village, island village
- (5) Streetscapes of post towns: post town
- (6) Streetscapes related to the seaport: port town
- (7) Streetscapes of merchant structures: merchant town
- (8) Streetscapes related to industry: silkworm raising, coal mining, manufacturing of salt, wax, or ceramics
- (9) Streetscapes of teahouses: amusement quarter
- (10) Streetscapes centered on shrines and temples: town in front of a shrine or temple, temple town, monastic town, shrine town
- (11) Streetscapes of samurai residences: castle town, samurai quarter

The official criteria of designating and classification the historic value and landscape value of the traditional groups of buildings, and indicate the expression of historic value or creating of townscape as the core area of the preservation.

The weakness of the wooden houses against the earthquake has already been widely recognized, however, the research on the reinforcement is still relatively slow. Over 6400 people were killed, and 41500 were injured and most of them are due to the collapse of old wood houses in the Kobe earthquake in 1995[2]. The record of the earthquakes that happened after Kobe earthquake (1995.5) indicates that Japan has already entered the period of high-frequency of seismic activities. Damaging earthquakes happened almost every year, and the Great East Japan Earthquake occurred afterwards in 2011. In addition, the outbreak of Nankai Trough Earthquake draws near, and the Inland crustal earthquakes will also take place around this time. Seismic damage seizes on the vulnerable part of the area and of the area and society severely, and the damage aspects vary from region to region.

The number of the designated important preservation districts is increasing steadily from 8 in 1976 to 98 in 2012, with great regional disparities in physical status, social context, and risk levels. The frequent seismic activities brought massive loss on people's life, properties, as well as the heritage value of traditional buildings and the conventional social- cultural oriented district investigation methods cannot provide sufficient evaluation on the physical- environmental aspects for the groups of traditional wooden houses in the preservation districts.

Though great efforts had already been done for preservation of IPDGHB, and there are also fruitful research achievements on the assessment of the structural performance for the traditional wooden buildings in Japan and it has scientifically deciphered many un-perceivable properties (strength, elasticity, durability, etc.) for the preservation objects, however, the achievements of structural research seem to be isolated from the mainstream research of the preservation of IPDGHB, and had moderate influence on the decision making process of the practical district preservation, especially in the early stages, and macro levels, like policy making and regional planning. Since the cultural-heritage- at- risk framework refocuses conservation attention from the curative to the preventive, from the short- term to the long- term [3], therefore the preservation plan and risk management for the IPDGHB should be proposed on the comprehensive consideration of both the value and risk, and the procedure of regional structural investigation should be standardized and the mechanism to integrate the regional structural investigation with conventional district investigation methods need to be clarified.

The strength of column is an important indicator to estimate the seismic behavior of traditional wooden buildings. JAS established by MAFF (Ministry of Agriculture, Forestry and Fisheries) describes timber grades which describe the lower limit of Young's modulus,

and together with it, the lower limit of strength of the material. However, the reliability of the un-aid vision inspection method of timber grade, a prevalent inspection method applied to existing timber objects is doubted, while the conventional device aided Young's modulus measurements with relatively higher accuracy all involve wounds and even destruction of the measured objects, which are difficult to be applied to the existing buildings. Therefore, it is important to improve the Young's modulus measurement based on the device aid methods in order to estimate the timber grade more accurately.

It is very difficult to evaluate the structural performance of traditional buildings one by one and estimate the vulnerability of whole area due to a large number of buildings and growing number of districts. Moreover, though the seismic performance of the groups of wooden buildings has been estimated for some districts and the hazards to the districts have been already identified, it is still difficult to assess the seismic vulnerability of the district without knowing the status of risk perception, preparedness related behavior of the inhabitants, and the implementation of the disaster- countermeasures is also related to the consciousness of the inhabitants. Combination of structural investigation with methodology based on social science becomes very important. Since the questionnaire survey is a well-established tool for acquiring information in district survey, it became an essential part of this survey method which can grasp the overall status of the building structure, maintenance and risk perception of inhabitants rapidly.

Before the regional structural research achievements are transferred into concrete disaster mitigation measures for the groups of traditional wooden building and inhabitants in important preservation districts, the complexity of the seismic risk should be fully recognized. Though the value of preservation objects is most frequently emphasized and assessed, in the life threatening condition, human life has indisputable priority in the decision making of emergency response in the meantime, the heritage value of IPDGHB should be fully considered, efforts to increase earthquake resistance must be based on adequate understanding of a building, its structural systems, construction materials and techniques, its evolution, history and conservation, its condition, its heritage values and its likely earthquake performance[3]. As Munoz-Vinas expressed his concern on the issue of scientific conservation lacking a coherent theoretical, epistemological body [4], there is still a gap between the structural research on built heritage and the preservation of IPDGHB. The knowledge of regional structural investigation requires to be well structured according to the characteristic of preservation objects and hazards, in other words, all the preservation objects and proposed intervention measures need to be classified into different levels, and the occasions and targets of different applications need to be clearly stated.

1.1.2 Objectives of research

The research of regional structural investigation is to grasp the regional structural characteristics and estimation of the seismic performance of the traditional buildings as well as the social context of the preservation district, and regional characteristics of structure, seismic performance, and vulnerabilities are summarized afterwards. To examine this method, we applied it to two coastal districts Ine and Yuasa, and disparities of two districts are demonstrated. Two approaches affiliated to the regional structural investigation, the Young's modulus measurement and questionnaire survey are explored. In order to massively apply to field survey of groups of traditional wooden buildings in preservation districts, a new Young's modulus measurement based on the improvement of Fakkop test is proposed. The results of questionnaire survey of seven districts are comparative studied and analyzed combined with the information of the disasters and the results of field survey on structural properties and deterioration status of houses.

1.2 Review on previous research

The review of the related literature focuses on 4 areas, the development of the structural inspection method for traditional wooden houses, and its application of the field survey for structural characteristics in preservation districts; the Young's modulus measurement for timber materials; the regional disaster vulnerability assessment based on questionnaire survey; and the research on risk management for cultural heritage.

1.2.1 Structural investigation on traditional wooden buildings

The estimation of seismic performance and structural mechanism of traditional wooden structures are explored based on experimental approach and theoretical analyses of wooden frames by Suzuki [5]. Hayashi applied the method of structural investigation for traditional wooden frame houses to the field survey in preservation districts with different level seismic risks [6-9], besides bringing the security issue with the heritage conservation together, this development demonstrates significance in several aspects, for one thing the number of structural inspection objects greatly increased, which brings the possibility for estimating the structural performance of the houses in different districts and provides references for districts planning in early stage, for another thing, more and more factors which influence the seismic performance of structures are taken into consideration, for instance, the interaction between houses, influence on environment etc; moreover, more comprehensive investigation approaches are adopted to explore the social context of the districts, correspondingly, seismic mitigation measures and retrofit methods were proposed with the reference on related theories and codes [10-11]. Some approaches are explored in detail during the development of

structural investigation method for groups of traditional wooden buildings, for example, the moisture content greatly influences the properties of wood material [12], the effectiveness of the application of structural investigation methods in real environment were verified and the effects of many parameters were examined such as temperature, humidity, and natural frequency on the wooden structure [14].

Though the methodology of structural investigation on wooden buildings gradually developed, its influence is still moderate in the research of district preservation, thus the method needs to be standardized and its relation with conventional district investigation method, and application occasions need to be clarified.

1.2.2 The Young's modulus measurement

There were many structures damaged by the past earthquakes [15], and Young's modulus of column is an important indicator to estimate the seismic behavior of the structure. Therefore, it is important to understand the material properties of the columns. The mechanical properties of 35 important Japanese woods are explored by Nankai [16]. Currently, there are mainly methods for Young's modulus measurement, Tapping-Tone Technique, stress wave velocity measurement and the other is bending test, and all of them involve damage to the test objects. Among these methods, the stress wave velocity measurement by the instrument Fakopp causes relatively smaller damage to the material. There are many researchers have explored the estimation of Young's modulus by the instrument Fakopp. Ishiguri examined stress wave velocity of the standing Cypress by Fokkopp, and the relationships between stress-wave velocity of standing trees and dynamic Young's modulus or modulus of elasticity in static bending of square timber were found [17]. Sasaki also measured the Young's modulus by Fakkopp test and examined the influence of material density and deterioration status of test results [18]. Minami applied the stress wave velocity measurement on standing trees, the propagation path of stress wave is studied, and the material properties are also tested [19-21].

Examination of the timber grade of column is significant for retrofit design [22-23]. To provide more practical references for seismic mitigation measures, the timber grades need to be demonstrated for the wooden buildings in the traditional districts. Though there are some guidelines for estimation the of the timber grade based on unaided view inspection method [24], however, the obvious errors of this method have been proved by experiments. Thus it is essential to conduct the non-destructive Fakopp test on existing wooden buildings for more precise measurement.

1.2.3 Questionnaire survey on habitation and disaster perception

Questionnaire is a fundamental tool for risk analysis for districts. It is difficult to assess the seismic vulnerability of the district without knowing the status of risk perception,

preparedness related behavior of the inhabitants, and the implementation of the disaster-countermeasures is also related to the consciousness of the inhabitants. And the relationship between the result of the perception and behavior of the inhabitants and the real status of their houses also need to be clarified. The regional structural investigation is already applied to the traditional districts at the same time of the questionnaire survey, and many structural properties are statistically analyzed [25-30]. The level of seismic risk of surveyed districts also described by related institutes [31-33].

To estimate the district vulnerability, many items need to be investigated by the questionnaire survey. The demographic status, as age of the inhabitants and family structure, etc. is one of major factors of estimating regional social vulnerability [34], relations of hazards and risk perception is explored by Siegrist [35]. Disaster preparedness and perception of risk is explored by Miceli, and the results indicated that disaster preparedness was positively associated with risk perception [36]. The factors demining inhabitants' preparedness for disasters examined by Takao, the findings show that the preparedness depends on ownership of a home, fear of flooding, and the amount of damage from previous disaster rather than previous experience with anticipation of disaster [37]. All the reviewed research on questionnaire survey on risk analysis is based on the social science, while lack the linkage with the concrete facts of real status of built environment which is critical to the districts vulnerability assessment.

1.2.4 Risk management for cultural heritage

As for risk management for cultural heritage, monumental work has been done to establish the framework and guidelines for risk management for cultural heritage by Stovel [38]; in this manual, the significance and principles of risk management for cultural heritage are interpreted, and sound approaches are discussed based on different types of disasters in terms of fire, earthquakes, flooding, armed conflict, etc. Other similar literature on heritage at risk, discusses disaster countermeasures based on the case study of major disasters, and also the preparedness discussed with long- term perspective [39]. The resource manual by UNESCO on managing disaster risks for world cultural heritage provides clearer and universal guidelines for heritage against disasters [40], while some studies are more targeted, as Murakami discussed the risk management for the built heritage based on the experience of the Great Hanshin Earthquake, and advice on restoration and recovery is given [41]. Some pragmatic theories and approaches which are related to the decision making of heritage management facilitate the establishment of integrated risk management framework for cultural heritage, like the series of research report on value assessment of cultural heritage [42], and guidelines on documentation.

The investigation has performed on damages of wooden houses from the earthquakes in

Northern Miyagi, and the role of hanging mud- wall to the seismic performance is explored. [44]. To clarify the impact of the structural regionality of the wooden houses on the maximum deformation angle during the strong shaking, seismic evaluation was carried out based on the equivalent performance response spectrum method [45]. The damage ratio of wooden houses and construction year [46], fragility function for wooden houses under pulsive ground motions [47], and earthquake countermeasures for wooden house considering durability and deterioration [48] are investigated.

1.3 Framework of research

The dissertation consists of six chapters (Fig 1.1). Chapter 1 is Introduction, including the background and objectives of the dissertation. In Chapter 2, the content of regional structural investigation is explained, and the process and results of investigation in Ine and Yuasa are used to exemplify the investigation method. Chapter 3 and Chapter 4, further interpret the details of two approaches of investigation, the improved stress wave velocity measurement and questionnaire survey. Chapter 5 discusses the preservation proposal for the traditional districts to against the coming Nankai and Tonankai earthquakes.

Major efforts were exerted onto the following aspects:

- (1) Method of regional structural investigation on IPDGHB: Method of overall investigation (Regional structural characteristics investigation, Ambient vibration measurement of the ground, Interview with the carpenters, Questionnaire survey) and detailed investigation (Interview with the inhabitants, Ambient vibration measurement of the houses and deterioration inspection of the houses); and results of investigation on Yuasa and Ine.
- (2) Improved stress wave velocity measurement: Three Young's modulus test methods (Tapping-Tone Technique, Fakopp test and bending test); the relationship between density and Young's modulus, improved system of Fakopp; uniform direction and revise formula; demonstration under existing wooden houses.
- (3) Questionnaire survey Questionnaire survey on habitation and disaster perception on six traditional districts: Method of questionnaire survey; seismic risk; results of questionnaire survey.
- (4) The application of seismic risk management for IPDGHB: Clarify the 2 the priority of the security and value, identify the characteristics of the hazards, and classify the managed objects and corresponding interventions into different levels, and applications on different levels and occasions.

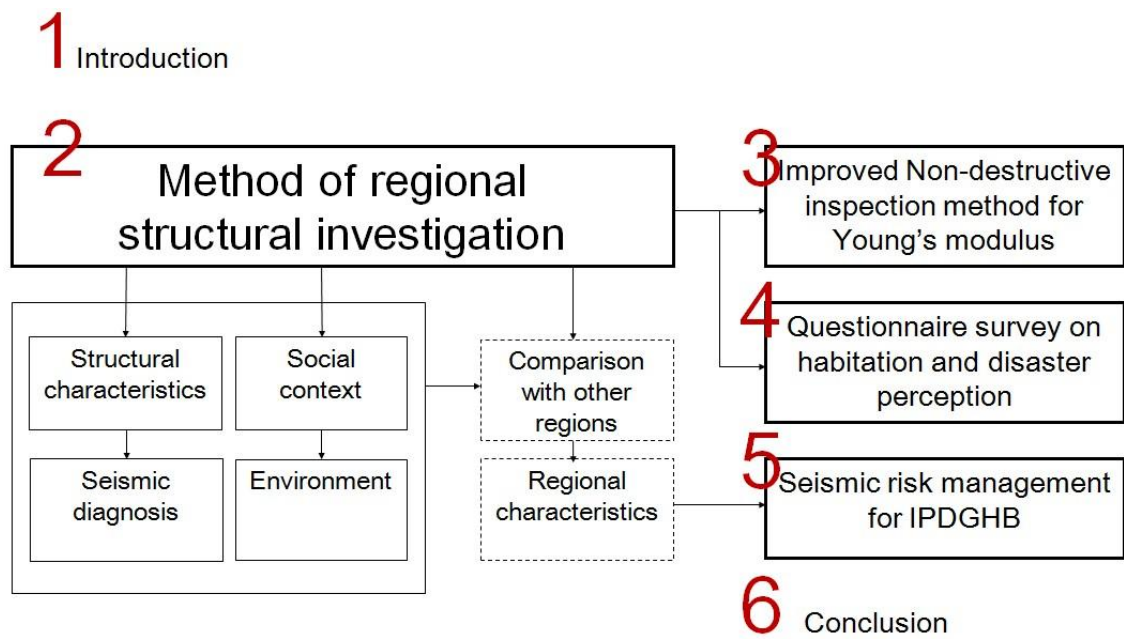


Figure 1.1 Content of the dissertation

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Relevant publications

Journal (Reviewed)

- [1] Namie, K., **Jiao, J.**, Sugino, M., Takiyama, N., Hayashi, Y.: Young's modulus estimation of timber by non-destructive test based on stress wave velocity measurement, *Journal of structural engineering, AIJ*, Vol. 78 No. 686, (2013) 833-838. (in Japanese)

Conference (Reviewed)

- [2] **Jiao, J.**, Yokobe, T., Takiyama, N., Watanabe, C., Kiyoko, K., Hayashi, Y.: Regional structural investigation for traditional districts preservation in Japan - case of Yuasa, *YILDIZ Technical University, ICOMOS ICORP International Symposium, Cultural Heritage Protection in Times of Risk, Challenge and Opportunities*, (2012)15-17.
- [3] Hayashi, Y., Takiyama, N., **Jiao, J.**, Nambu, Y.: Design of seismic countermeasures considering local characteristic of cities and buildings, *Design Symposium 2012*. (in Japanese)

Conference Paper (Abstract Reviewed)

- [4] Takiyama, N., **Jiao, J.**, Namie, K., Nambu, Y., Hayashi, Y.: Timber grade evaluation by improved stress wave velocity measurement, *Proc. of International Symposium on Earthquake Engineering, JAEE*, Volume 1, (2012).

Other Conference Papers

- [5] Okazawa, R., Jiao, J., Kimura, Y., Morii, T., Takiyama, N., Watanabe, C., Yasuhiro, Y.: Seismic risk perception of Inhabitants in six districts ,JAEE, (in Japanese), (2013) 405-406.
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- [1] Nambu, Y., **Jiao, J.**, Takiyama, N., Watanabe, C., Yasuhiro, Y.: Regionality of structural characteristics in traditional wooden houses, *Journal of structural engineering*. Volume 59B, (2013)585-592. (in Japanese)
- [2] Saratani, A., Mizutani, Y., **Jiao, J.**, Hayashi, Y.: Earthquake countermeasures for local wooden house considering durability and deterioration. *AIJ J. Technol. Des.* Volume 18, No.39, (2012) 427-430. (in Japanese)

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- [3] Nambu, Y., **Jiao, J.**, Takiyama, N., Hayashi, Y.: Quantification and interregional comparison of structural characteristics of traditional wooden houses in Japan, *Proc. of International Symposium on Earthquake Engineering, JAEE*, Volume 1, (2012)

Chapter 2 Methods of structural investigation on traditional wooden buildings

2.1 Introduction

Districts of groups of traditional buildings are extensively existing in Japan with various regional characteristics which highlight the Japanese traditional wisdom and constructing skills. As the historic value of traditional districts had been widely recognized, the category of important preservation districts of groups of traditional buildings (IPDGHB) was introduced by the amendment of the Law for Protection of Cultural Properties of Japan in 1975. Important Preservation Districts for Groups of Traditional Buildings are designated according to one of three criteria: a) Groups of traditional buildings that show excellent design as a whole; b) Groups of traditional buildings and land distribution that preserve the old state of affairs well; c) Groups of traditional buildings and their surrounding environment that show remarkable regional characteristics [1]. By far the number of the designated districts has increased to 98 [2].

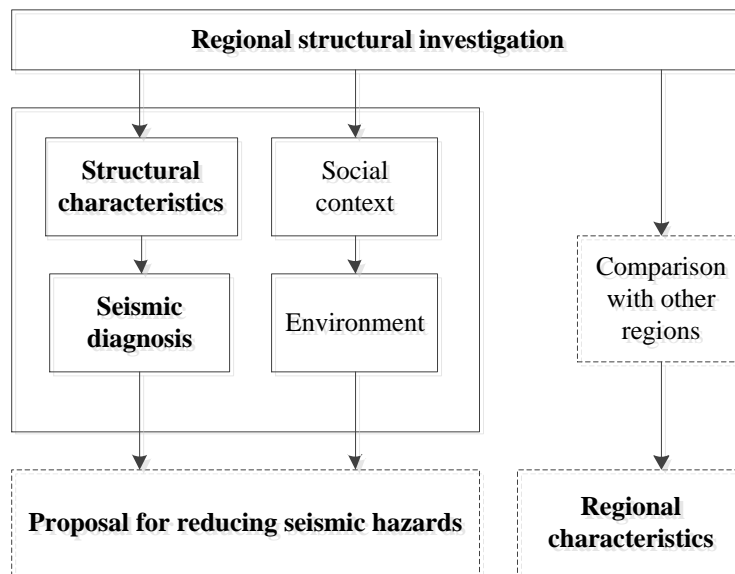


Figure 2.1 Framework and prospect of regional structural research

Though the social-cultural value of traditional districts have been intensively investigated and manifested through conventional district investigations, the investigation of traditional districts on physical- environmental dimension is still insufficient. The records of the earthquakes indicate that Japan has already entered the period of high-frequency seismic activities and according to the damage statistics of Japan, most of fatalities due to the

structural failure of old wooden buildings. Thus it is important to estimate the seismic performance of the buildings as well as the interests of conducting seismic retrofit for the houses of the house-owners.

Table 2.1 Content of investigation

		Content
Overall investigation	Structural properties	<ul style="list-style-type: none"> • Structural type • Material, etc
	Questionnaires	<ul style="list-style-type: none"> • Demographical information • Age, style, usage of the buildings • Structural types, material • Maintenances • Disaster experiences of the inhabitants and properties • Disaster perception of the inhabitants, etc
	Ambient vibration measurement	<ul style="list-style-type: none"> • Natural frequency of the ground
	Interviews with carpenters	<ul style="list-style-type: none"> • Structure, material of the buildings • Constructing technique, etc
Detailed investigation	Interviews with inhabitants	<ul style="list-style-type: none"> • Information of their families and houses • Change of the community • Maintenance of their houses • Disaster experiences and risk perception
	Ambient vibration measurement	<ul style="list-style-type: none"> • Natural frequency of the houses
	Deterioration investigation	<ul style="list-style-type: none"> • Decay • Termite damage • Moisture content, Young's modulus and inclination of column, etc.
	Investigation on structural properties	<ul style="list-style-type: none"> • Material and dimension of components • Joints, etc

It is very difficult to evaluate the structural performance of traditional buildings one by one due to the large number of buildings and the growing number of designated preservation districts. The traditional buildings reflect the social, technical, environmental context of the district, and share the same regional characteristics. We have proposed an onsite survey method of traditional districts for both structural properties of the wooden houses and social context, thus the regional structural characteristics could be summarized and disaster

countermeasures could be proposed [3]. Figure 2.1 indicated the framework and prospect of regional structural research of traditional districts.

In order to deal with a large number of buildings, the regional structural investigation on traditional districts is divided into 2 parts, the overall investigation and detailed investigation. The overall investigation is conducted to grasp the status of a whole district, and the detailed investigation is performed on some of the individual buildings to further explore the structural properties, performance and status of inhabitants. Table 2.1 shows the items of the investigation [4].

2.2 Overall investigation

2.2.1 Regional structural characteristics

The overall investigation on regional structural characteristics is applied to all the houses in investigated district for the structure types, usage, and surroundings, etc. which can be quickly observed and measured from the outside of the houses. Some items like types of structure, types of buildings, position of ventilation, distance between buildings, etc. are inspected as shown in Table 2.2.

Table 2.2 Overall investigation sheet

1	Number of building	()				
2	Structure types	Timber	Steel	RC	Other ()	
3	Number of stories	1	1.5	2	3	
4	Style	Traditional	Modern			
5	Roof types	Tsumairi	Hirairi	Other ()		
6	Usage	Residence	Shop	Storage		
7	Outer wall	Siding	Horizontal	Vertical	Plaster wall	
8	Ventilation	Under floor	Roof			
9	Width of eave	() cm				
10	Distance between buildings and usage of land between buildings					
	Right () cm	Parking	Vacant lot	Cannel	Road	Other
	Left () cm	Parking	Vacant lot	Cannel	Road	Other

2.2.2 Ambient vibration measurement of the ground

Ambient vibration measurement is conducted to obtain the natural frequency (f) of the ground of the district as a whole. In order to estimate the seismic performance of the ground, the geographical condition of the ground is also taken into consideration.

We use seismometer GPL-6A3P by Akashi manufacturing to conduct the ambient vibration measurement. Each accelerometer has three channels, one vertical and two horizontal directions and they work simultaneously. All accelerometers are synchronized by using GPS

signals. Sampling frequency is 100 Hz. Each time series data are divided into segments with duration times of 40.96s. To minimize errors of noise, the ensemble mean is calculated and the fast Fourier transform (FFT) is applied to the ensemble mean [5]. For each measurement, we take the peak frequency of the dominant period of the H/V spectrum of micro tremor records as the predominant frequency of the ground. And we applied fast Fourier transform (FFT) on the records, and obtained the Fourier spectral ratio through dividing the amplitude of NS and EW directions by UD direction respectively.

2.2.3 Interview with the carpenters

Carpenters are introduced by the municipality for the interview. The interviews focus on the material of column and beams, typical constructing methods and techniques, joints of column and beams, maintenance of houses and disaster preparedness.

2.2.4 Questionnaire survey

The questionnaire survey aims at clarifying the regional structural characteristics, way of living, situation of maintenance, construction methods, styles and scales of the houses, the status of housing maintenance and the difficulties on disaster prevention.

2.3 Detailed investigation

The detailed investigation is applied to individual houses for the structural details, performance and information of owners. In most cases, 10- 15 houses have been investigated in 4 days.

2.3.1 Interview with inhabitants

The interview with the inhabitants focus on the following aspects: history and the maintenance of houses, disaster experience, information of inhabitants, and changes of neighborhood. The conversation with the owner of the house is taken the same time of other measurements and inspections being conducted in the house (Fig 2.2 (a)).

2.3.2 Ambient vibration measurement of the houses

In order to identify the vibration characteristics of the houses, the ambient vibration measurements had been conducted for the selected houses (Fig 2.2 (b)). We use the same device as the ambient vibration measurement of the ground. More than two accelerometers were set on the second floor of each house to identify torsional mode and one accelerometer was set on the soil surface [6].

2.3.3 Investigation on structural properties

The material and dimension of structural components are important parameters when structural performance of house is estimated. The yield base shear coefficient (C_y) is used to evaluate the seismic capacity of a wooden house as a whole from the ridge and span directions respectively [7]. The yield base shear coefficient (C_y) can be calculated from the horizontal restoring force of the 1st-floor at the 1/30 rad of deformation angle (Q_y) divided by the total weight of the house which includes the fixed and live loads which can be simply calculated from the 1st floor plan of houses [8]. In the investigation on structural properties, the structure of houses is recorded by photos, cartographic and architectural drawings. In addition, the typical structural details and joints have been measured and studied.

2.3.4 Deterioration inspection



(a) Interview

(b) Ambient vibration measurement



(c) Inclination measurement

(d) Young's modulus measurement

Figure 2.2 Detailed investigations

Deterioration often compromises the capability of wood structure. The deterioration of

wood structure can be the result of the physical process (overloading, ground motion, etc.), and biological process (fungus, termites attacks, etc) [9]. Funguses start to feed on wood when the wood members are prolonged exposure to moisture, and are most active when moisture content of wood is between 30%-60% [10]. The deterioration inspection involves measuring the inclination(Fig 2.2 (c)), Young's modulus and moisture content of the columns, checking the position and numbers of ventilations, under floor space and occurrence of decay and termite damage as well as the repair work of house (Fig 2.2 (d)).

2.4 Investigated districts

2.4.1 General information

(1) Ine

The evidence of human existence in Ine can be traced back to the 6th century, as iron wares and earth wares were discovered in Oura Nakao buried mound in 1981. Ine got prospered since the late 9th century as the haven and trading post, owing to the establishment of Manorialism and coastal trade with China. Since this area enjoys high forest cover and rich aquatic resource, and halieutics was well developed in Ine. The period between the late 19th century and the middle of the 20th century was the heyday of fishery in Ine, and majority of boat houses we can see today were built in that period. In 2005, Ine was designated as important preservation district of groups of traditional buildings, and classified as fishery town [12].

The preservation area (320.1ha, East-West: 2650m, South-North: 1700m) in Ine is extending along the Wakasa Bay from east to west including Hide district, Takanashi district, Hirata district, Tateishi district, Nibi district, and Kameyama district. There are mainly two typical traditional wooden buildings related with fishery in Ine, one is the main house along the mountain side and one is the boat house (funaya) along the sea side. Both of the main house and boat house are constructed with gabled roof (kirizumazukuri style); entrances of main houses are constructed parallel to ridges of the roofs (hirairi) and there are entrances along the gabled sides for the boat houses (tsumairi) and openings facing the sea for mooring. (Fig 2.3)

(2) Yuasa

Since Heian Period, Yuasa, one of the pilgrims paying homage by Kamano road, had flourished. At the same time as the transport hub of sea and land, it led to the prosperity of the fisheries and trading. During the period of Kumakura, the miso manufacturing technology was learned from China and soy sauce was produced by chance. Since then the place has been known as the birthplace of Japanese soy sauce. In 2006, Yuasa was designated as the

important district of groups of historic buildings, and classified as the brewing town characterized by this period of history [13].

The preservation area (6.3ha, East-West: 400m, South-North: 280m) in Yuasa comprises several districts as Kita-machi, Kajiya-machi, Naka-machi, and Hama-machi where the brewing industry was flourishing at the end of the 16th century. Nowadays, the traditional streets, lanes, town houses related to brewing industry and storages with gabled roofs (Kirizumazukuri style) which are tiled with alternating flat and rounded tiles (Hongawara-buki), and lime plastered walls with decorative lattice (Mushiko window) all highlight the local characteristics of this districts. (Fig 2.4)



Figure 2.3 Detailed investigated house in Ine



Figure 2.4 Detailed investigated house in Yuasa

2.4.2 Current status of two districts

(1) Location and traffic

As shown in Figure 2.4 Ine is located in Yosa District of the north Kyoto prefecture, northwest end of Wakasa Bay and south east to Sea of Japan, and is adjacent to the north of Miyazu city and east of Kyotango city. Ine is quite isolated from big cities to some extent, since there is neither airport nor rail way available near Ine. It takes 2.5 hours to go to Osaka or Kyoto by car. The only public transportation which can be utilized to have access to Ine is Tango Kairiku Koutsu bus which combines the Amanohashidate Bus Station and Miyatsu Railway station.

Yuasa is located in the middle of Wakayama Prefecture, and is to the south of Osaka and to the west of Nara. Yuasa is close to the west shore, surrounded by sea and hills. Compared with Ine, it is easier for people to live in Yuasa to have to access to other cities owing to the JR Kisei rail way across the town.

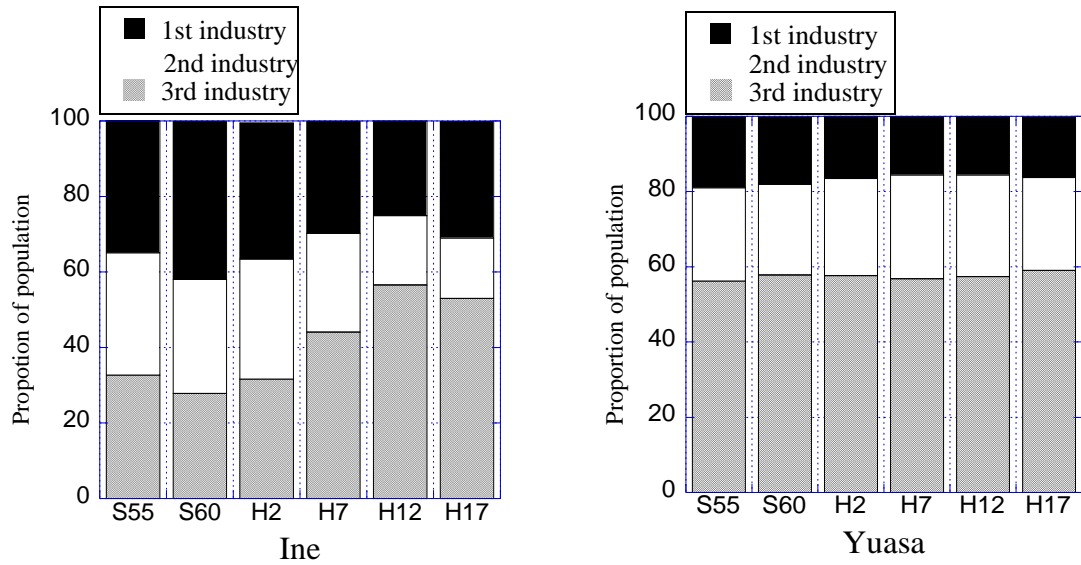


Figure 2.4 Location of Ine and Yuasa

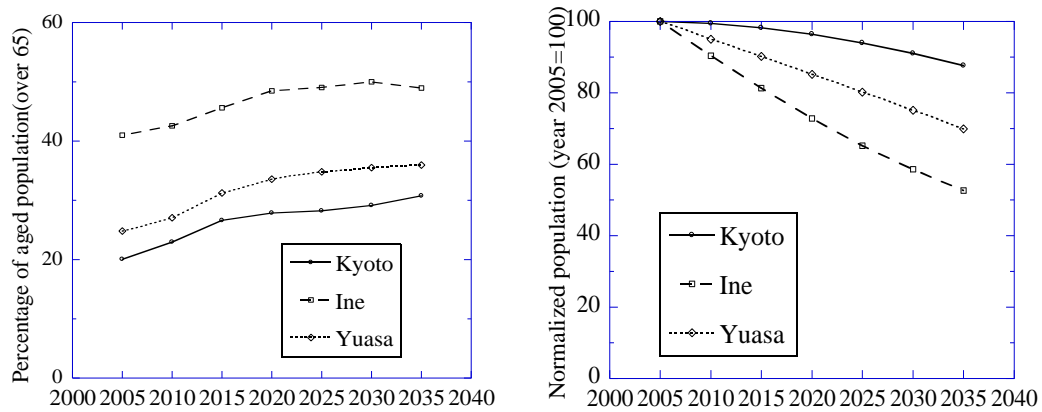
(2) Industry

Figure 2.5 (a) shows the proportion of working population of different industries in Ine and Yuasa based on national census (S55-H17). The primary industry is agriculture, forestry and fishery, the secondary industry is manufacturing, mining and construction, and the tertiary industry is transportation, information and communication, electricity, gas and water supply. In Ine, the employed population is decreasing, and the ratio of employment in secondary industry has drastically declined, while the proportion in tertiary industry is constantly growing. The amount of fishery production and the amount of employee based on fishery has been greatly reduced. While the number of tourists visiting Ine is increasing, especially in 1993 when Ine was the scene of TV drama. The situation is similar in Yuasa. Percentage of population employed in primary and secondary industry has decreased and more people engage in tertiary industry. The orange and fish account for the main production of Yuasa, but now both the number of employed people and amount of outcomes has declined [14].

As shown in Fig 2.5 (b), the trend of depopulation is quite obvious both in Yuasa and Ine compared with Kyoto. The situation will be particularly serious in Ine, and the population will be halved of 2005 within 30 years. The problem of aging population is also quite severe in Ine, while Yuasa is relatively better. Aging population (over 65) will gradually increase to half of the total population in Ine in 2030 [15].



(a) Proportion of population by industries



(b) Depopulation and aging population

Figure 2.5 Industry and population by industries

2.4.3 Hazards

(1) Natural disasters

Figure 2.6 illustrates the hazard curve of 3 important preservation areas (relationship between the maximum velocity of the engineering base and probability of exceedance in 30 years), which means the higher of probability of exceeding of the maxim velocity, the higher the risk becomes (National Research Institute for Earth Science and Disaster Prevention). And it can see that Yuasa is confronting much higher risk of seismic risks than Kyoto and Ine. The seismic damages in Yuasa may come from both Epicentral earthquake and Subduction earthquakes along Nankai trough. In Subduction earthquakes, large damages associated with ground motion and tsunami will occurs [15]. Though Ine is also a coastal district, it has lower risk of Tsunami owing to the Aoshima which acts as a natural breakwater and large waves can

be reduced when approaching the district.

Moreover, Yuasa is easy to be as affected by typhoon which lands from Kyushu passes through Japan, and often brings heavy rain and flood. Houses in Ine may be damaged by landslide which spread in a narrow space along the bay and are closing to the mountains.

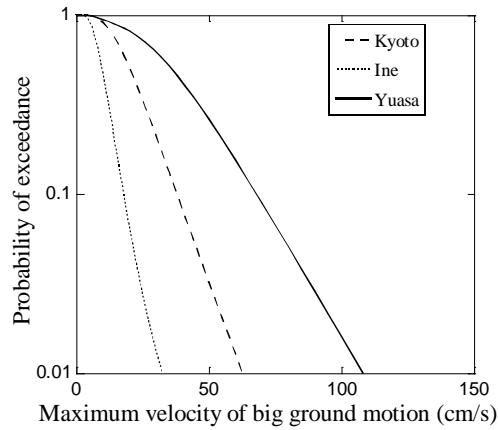


Figure 2.6 The hazard curve of 3 districts

(2) Other hazards

Besides the natural disasters, the road between boat houses and main houses in Ine is very narrow, which brings risks when fire or earthquakes occurs. Old buildings may collapse and block the road, thus it is difficult for inhabitants to evacuate or for fire trucks to approach [16].

2.5 Results of investigation

2.5.1 Site condition

(1) Geographical condition

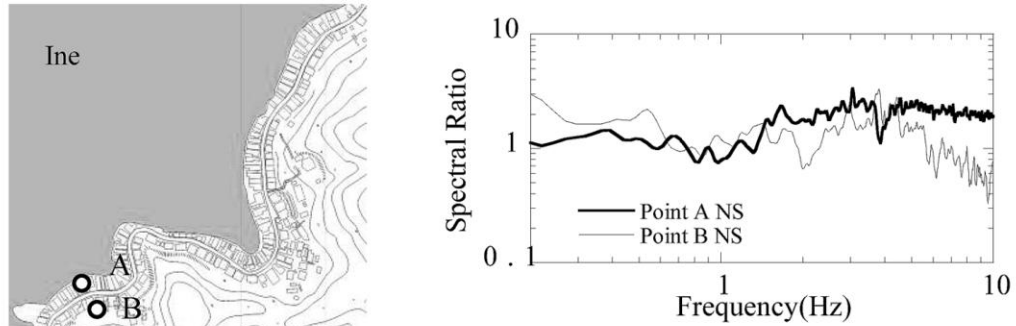
Both Ine and Yuasa are very close to the sea, however, they are confronting different kinds of disaster risks. The ground in Yuasa is very soft, and the ground motion velocity tends to be amplified during the earthquakes. Whereas the probability of seismic activities is relatively lower in Ine, and the ground condition is much better, however, the buildings are confronting the threats of landslides from the hills nearby.

(2) Predominant frequency of the soil

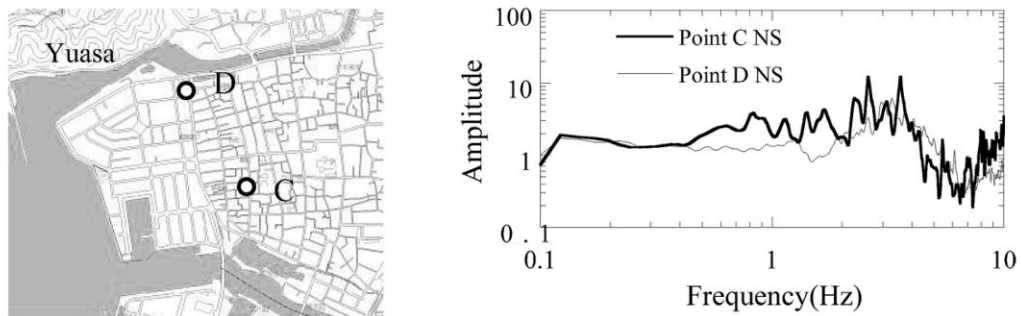
The ground surface of Tateishi area in Ine is approximately 10m. The natural frequency is smaller for the ocean than hill side in Niji area. However, there is no significant difference between the sea side and hill side for the Niji area as shown in Fig 2.7 (a).

The altitude of Yuasa traditional district is between 7- 10m, and the natural frequency tends to be higher in the places with relatively higher altitude. The natural frequency of the traditional district is around 2-3 Hz (Fig 2.7 (b)), which is close to the value of natural

frequency of the houses, thus the amplitude of vibration will amplify during the earthquake due to the softness of the ground. In addition, in 1854 the last Nankai earthquake, tsunami affected half of the designated district. The coming Nankai earthquake will be fiercer than the previous one, thus the whole designated district is in danger inundated caused by tsunami.



(a) Location and spectral ratio of points A and B



(b) Location and amplitude of points C and D

Figure 2.7 Natural frequency of the ground in Ine and Yuasa

2.5.2 Structural characteristics

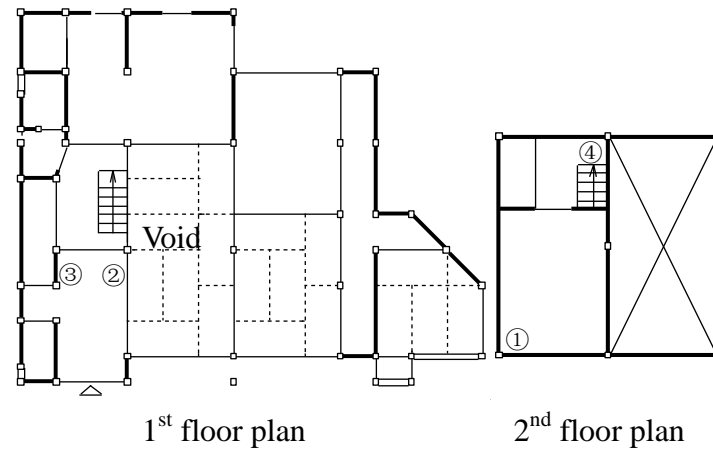
(1) Material

In Ine the columns and foundations of boat houses (Funaya) are made of Castanopsis, beams are made of Japanese pines. The Castanopsis is stronger when it is wet, thus it is suitable to be used on boat houses. However, the new constructed boat houses are made of Cypress, and Japanese pine substituted for Oregon pine for both the main house and boat house. Cedar and Cypress are used as columns of main houses. Zelkova is used as mainstay of main building sometimes.

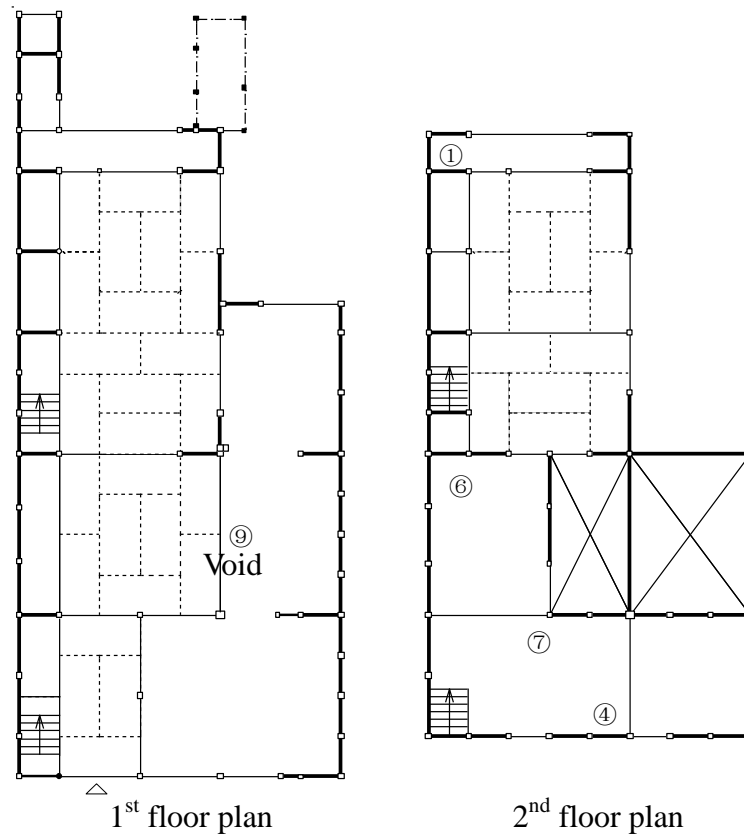
In Yuasa the material of most center columns is hemlock, and some other center columns are made of cypress because of the rising price of hemlock in recent years. The hemlock used to be taken from surrounding area; however they are not available nowadays. The beams were always made of pines in the past while now made of cedar. Compared with the traditional mud

walls which were placed about six months after mud was mixed with straw, the current mud walls are weaker in water. Only a few people master this kind of constructing technique nowadays in Yuasa, and there is one shop that engages in building mud walls. The use of mud walls becomes less among the new constructions, and the material of old mud wall is reused sometimes.

(2) Space and frame



(a) KM house in Ine



(b) TY house in Yuasa

Figure 2.8 Plans of houses in Ine and Yuasa



(a) Ine

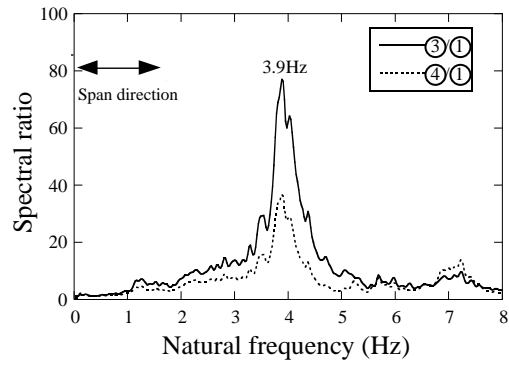
(b) Yuasa

Figure 2.9 Interior of the houses

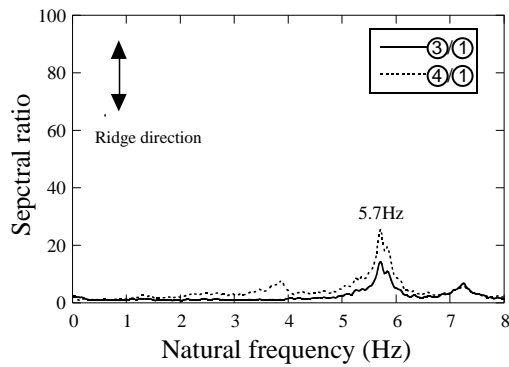
The plan form of houses Ine is called Tango type which widely spread in Northwest of Tango area. Typical Tango type house is a set of rooms under the gabled roof with entrances parallel to ridges of the roofs (Kirizuma Hirairi) as earthfloor (Doma) next to a spacious living room (Daidokoro) and parallelized with another two bedrooms in a row (Fig 2.8 (a)). In Yuasa there is earth floored passage (Tooriniwa) along a row of rooms in majority houses, and the arrangement of the rooms is based on the pattern of two rows of two rooms (Fig 2.8 (b)).

As shown in Fig 2.9, there are many cases in Ine and Yuasa there are more walls in the second floor of the houses, while there are fewer walls in living room of the first floor in order to make the rooms more spacious as illustrated in Fig 2.8. The continuous columns rarely exist. Usually the columns are divided by the beams or other horizontal structure. Thus the horizontal resistance is very weak of this typical structure. The big hanging walls and void space can be found in both of the districts, and the big hanging walls are distributed around the living room (Hiroma) as a square in Yuasa, and are distributed around the earth floored passage (Tooriniwa) as cross in Ine. This may due to the void space above the kitchen, and there is no floor on the second floor of the void space, so the horizontal force could not be transferred. In addition, the columns connected with the hanging walls are easy to be cracked. Therefore, as for this typical structure with many hanging walls, we need to deal with the horizontal force which could be burden to the hanging walls, to prevent the break of column. Though local constructing method is part of district preservation, the carpenters and designer need to full aware the weakness of the conventional constructing method and make improvement to upgrade the structure performance for the traditional buildings.

(3) Vibration characteristics

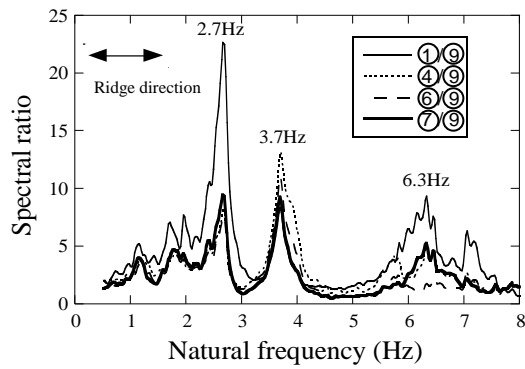


(a) Span direction

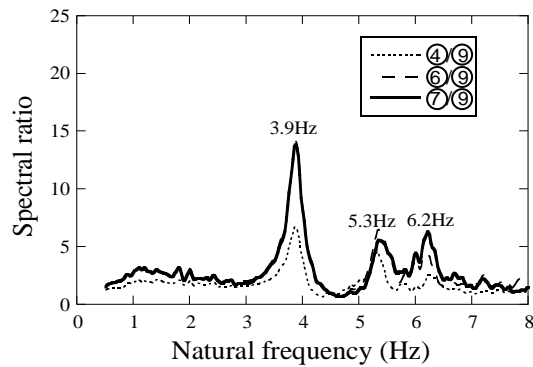


(b) Ridge direction

Figure 2.10 Spectral ratio of natural frequency of KM house in Ine

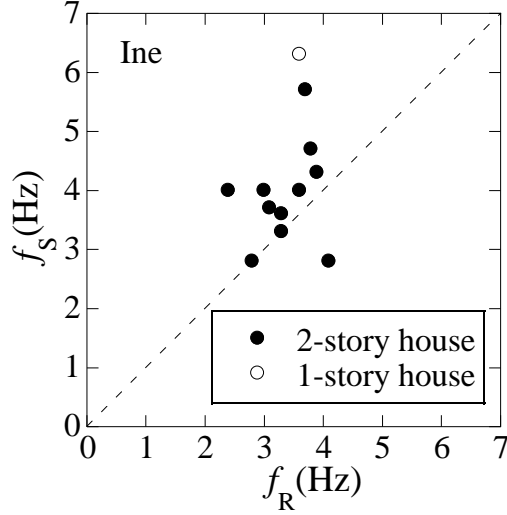


(a) Ridge direction

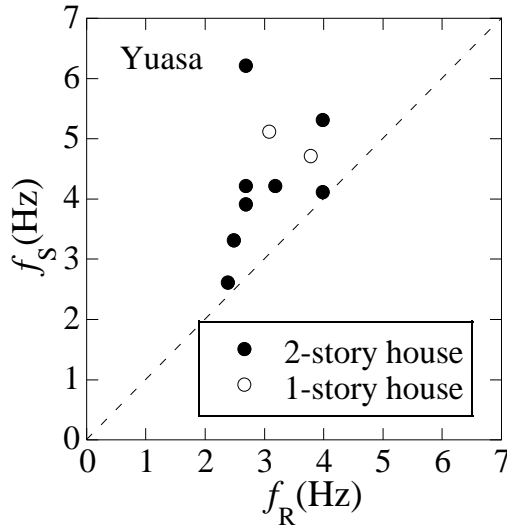


(b) Span direction

Figure 2.11 Spectral ratio of natural frequency of TY house in Yuasa



(a) Ine



(b) Yuasa

Figure 2.10 Natural frequency of building in Ine and Yuasa

We use seismometer GPL-6A3P by Akashi manufacturing to conduct the ambient vibration measurement. Each accelerometer has three channels, one vertical and two horizontal directions and they work simultaneously. All accelerometers are synchronized by using GPS signals. Sampling frequency is 100 Hz. Each time series data are divided into segments with duration times of 40.96s. To minimize errors of noise, the ensemble mean is calculated and the fast Fourier transform (FFT) is applied to the ensemble mean [5]. For each measurement, we take the peak frequency of the dominant period of the H/V spectrum of micro tremor records as the predominant frequency of the ground. And we applied fast Fourier transform (FFT) on the records, and obtained the Fourier spectral ratio through dividing the amplitude of NS and EW directions by UD direction respectively. More than two accelerometers were set on the second floor of each house to identify torsional mode and one accelerometer was set on the

soil surface.

Figure 2.10 and Figure 2.11 show the spectral ratio of natural frequency of KM house in Ine and TY house in Yuasa respectively to exemplify the measurement. The location of the accelerometers are indicated in Fig.2.8, KM house (1st floor: ①②, 2nd floor:③④), TY house (1st floor: ⑨, 2nd floor:①⑦⑥④), and torsional vibration may occur during the earthquakes.

Figure 2.12 shows the natural frequency of the buildings in Ine and Yuasa by the ridge direction (f_R) and span direction (f_S).The natural frequency of main houses in Ine is 2.4–4.1 Hz for span direction and 2.8–6.3Hz for ridge direction. As for boat house, the natural frequency is 2.2–7.0 Hz for span direction and 2.2–3.9 Hz for ridge direction. The natural frequency of houses in Yuasa is close to the value of natural frequency of ground, therefore the vibration will be amplified during the earthquake. The span direction of natural frequency of the houses is between 2.0-4.0 Hz, and the ridge direction of natural frequency is 2.6-4.1 The natural frequency is larger for the span direction than the ridge direction for both of the districts.

2.5.3 Maintenance status

(1) Moisture content of column

Figure 2.13 indicates the average moisture content of column in main houses and boat houses in Ine, as well as under floor and 1st floor of houses in Yuasa. The moisture content of column under floor in Yuasa and the 1st floor of boat house in Ine is very high, approximately 30%, and more ventilations are strongly recommended for these houses. In general the moisture content is higher in the seaside of boat house.

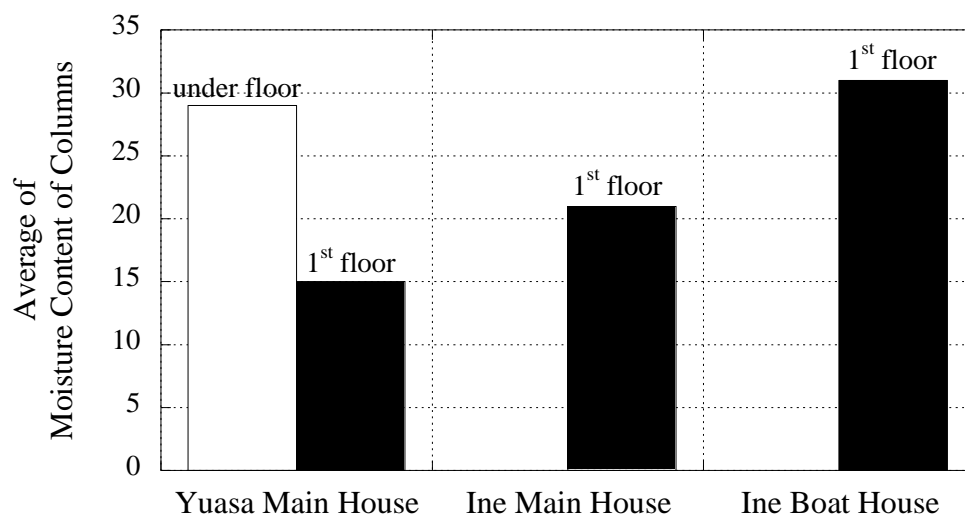


Figure 2.13 Average moisture of houses in Ine and Yuasa

(2) Maintenance activity and preparedness

Half of the investigated houses in Ine are around 100 years old. All the houses have been

renovated in terms of replacement of the roof material, maintenance of the pipes in kitchen and toilet. The reconstruction is often conducted when events happen, such as wedding, or a family member moves out. As for maintenance, the ventilation of the bath room and weeding is often conducted, but there is no effort for mitigation of termite damage and decay. Besides the maintenance applied to daily basis, many houses raise the tatami and do the thorough cleaning every year; however the work is difficult to be carried out sometimes, because there is no young man to help do the work. Many houses have cooperated carpenters. The regulations of renovation and reconstruction became strict, after Ine has been designated as important preservation district. In addition, few houses done seismic retrofit and there is no plan to do this in the future, the reasons for this is they think there is no problem with the ground condition and the houses during the earthquake, and their offspring may not live in the houses in the future.

In Yuasa there are some beams of the houses that stretch out of the roofs and get rainwater into the room, and are easy to do damage and make the roof and wall decay. Old tiles are frequently reused on the roof, but lacking of necessary regular replacement and inspection. Almost all the houses have been damaged by termites, and some counter measures have already been taken like smoking and spraying. Panels are used to increase the strength of plastered walls, and bolts are used in the junctions. Also, in condition the pillars and horizontal structure are rotten, new pillars are added without removing the original from economic consideration. The limited budget and aging problems make the inhabitants more hesitate to conduct seismic retrofits for their houses. When typhoon or earthquake occurred, the carpenters went to inquire into the houses they used to work on, while other houses had been ignored. However, the understanding of the state of the houses diverges between the carpenters and inhabitants, and usually the actual condition is much poorer than expected if they tried to start the retrofit.

2.5.4 Structural properties

Based on the results of investigation of structural properties, several indices which determine the structural performance of houses are calculated and compared between districts as 1st floor area (A_1), weight and height of houses, number of column in 1st floor, dimension of column and yield base coefficient (C_y) for ridge direction and span direction of the houses as shown in Fig 2.14. The C_y (yield base shear coefficient) is used to evaluate the seismic capacity of a wooden house as a whole from the ridge and span directions respectively. The yield base shear coefficient (C_y) can be calculated from the horizontal restoring force of the 1st-floor at the 1/30 rad of deformation angle (Q_y) divided by the total weight of the house which includes the fixed and live loads. The dimension of column is usually 120mm×120mm in Yuasa, while the dimension of column is usually 135mm×135mm in Ine.

Although the seismic hazard is not severe in Ine, there are many houses with the yield base coefficient less than 0.2. Compared with two districts, there is no significant difference of the values of W/A_1 and H , and the ratio of D_{c1} to W/N_{c1} is larger in Yuasa. C_y is relatively larger of span direction for both of the districts, and houses in Ine are relatively weaker.

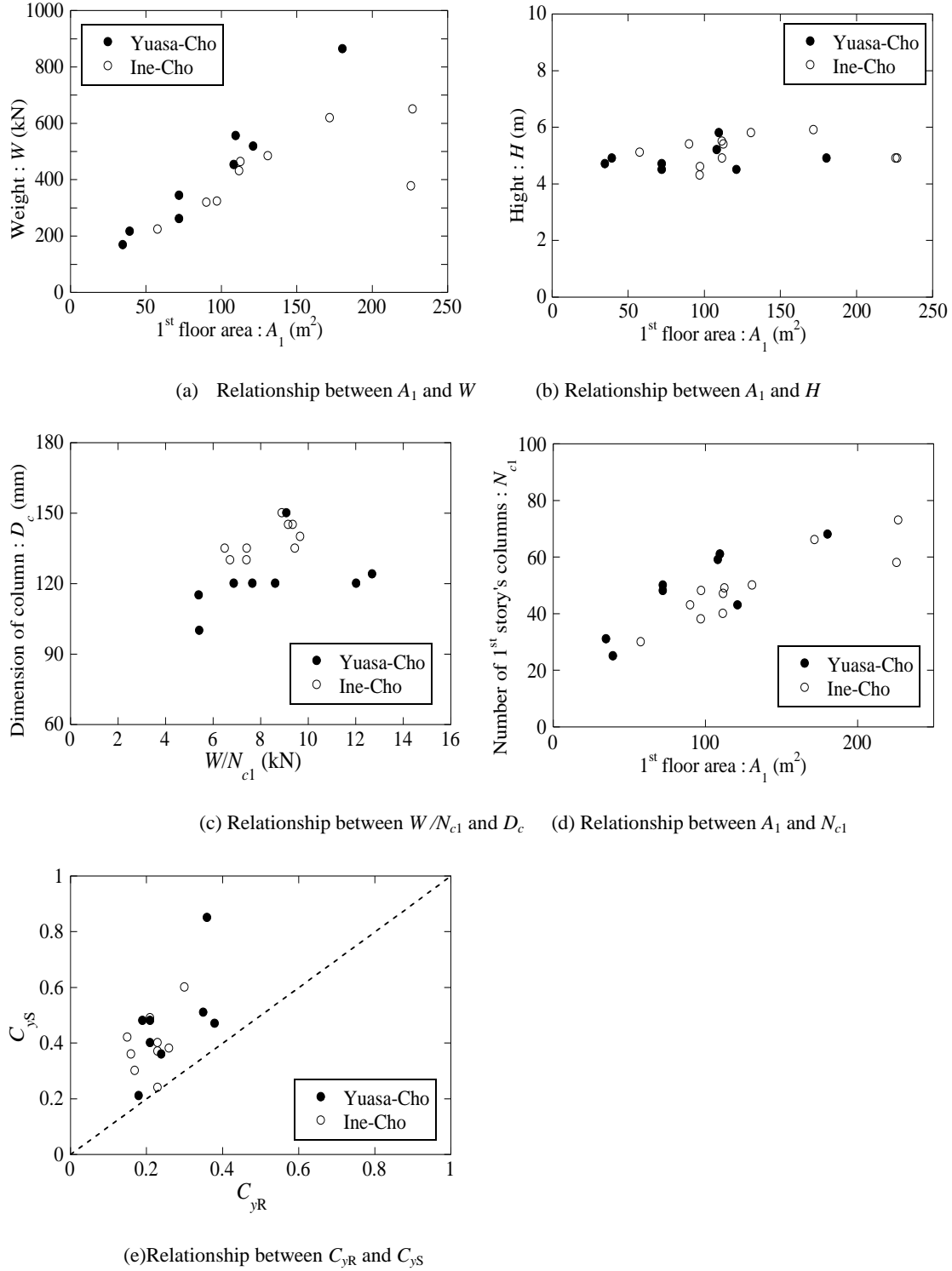


Figure 2.14 Structural properties

2.6 Conclusion

Method of structural investigation on IPDGHB is introduced in this paper as a supplementary approach which can be combined with conventional district investigation methods to establish integrated evaluation system of traditional districts considering both values and risks.

Two coastal preservation districts Ine and Yuasa are investigated and compared. Regional structural characteristics and district vulnerability are different from region to region and should be taken as important indices during decision making of districts preservation.

- (1) Both of the Ine and Yuasa are confronting the issues as depopulation and aging of population, and recession of primary and secondary industries. Problems are more severe in Ine.
- (2) Seismic risk is higher in Yuasa, while the preparedness is not enough.
- (3) Comparing the structural characteristics of traditional buildings in 2 districts, though there is no significant difference of the values of W/A_1 and H , some differences can be observed as follows:
 - The dimension of column is usually $120\text{mm} \times 120\text{mm}$ in Yuasa, while the dimension of column is usually $135\text{mm} \times 135\text{mm}$ in Ine.
 - Although the seismic hazard is not severe in Ine, there are many houses with the yield base coefficient less than 0.2.
 - The moisture content of column under floor in Yuasa and the 1st floor of boat house in Ine is very high, namely the risk of deterioration is higher.
 - The big hanging walls and void space can be found in both of the districts, and the big hanging walls are distributed around the living room (Hiroma) as a square in Yuasa, and are distributed around the earth floored passage (Tooriniwa) as cross in Ine. The horizontal force could not be transferred due to the void space.

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Chapter 3 Development of non-destructive testing method of column in existing wooden buildings

3.1 Introduction

There are many traditional wooden structures in Japan. In recent years, earthquakes have happened frequently, thus many structures have been damaged [1]. So it is very important to understand about seismic behavior of them. In seismic performance estimation of wooden structures, it is needed to find material characteristics such as Young's modulus, density and so on. In addition, the breaking of column sometimes directly leads the collapse of the house, thus, it is very important to estimate the bending strength of the columns for the seismic diagnosis. The material characteristics of standing trees are measured by some non-destructive tests. And there are some researches about these [2-7]. However, it is difficult to apply these tests to timbers or members of existing wooden houses because most of them involve a slight wound and some tests involve destruction. In this paper, we propose to improve measuring method of material characteristics for timbers without even a slight wound at existing wooden structures and further apply it to estimation of bending strength of the columns.

3.2 Material test methods

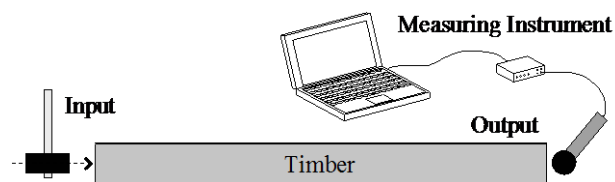


Figure 3.1 Tapping-Tone Technique

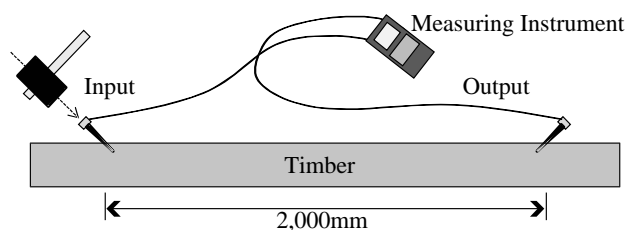


Figure 3.2 Traditional stress wave velocity measurement by Fakopp

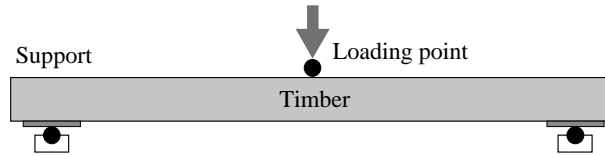
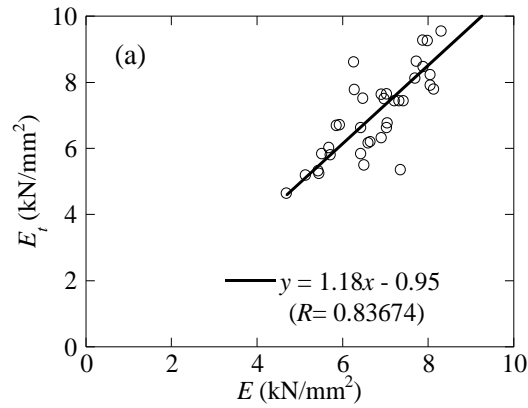
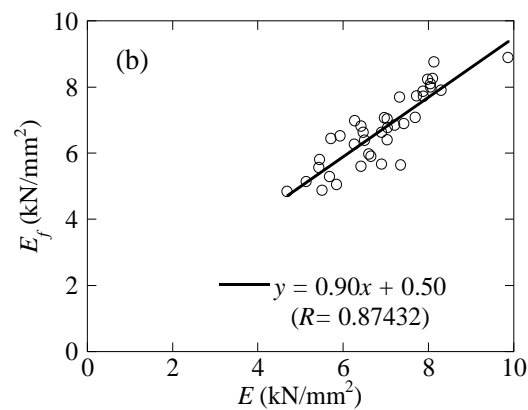


Figure 3.3 Three-point bending test



(a) Tapping-Tone Technique



(b) Stress wave velocity measurement by Fakopp

Figure 3.4 Relation between Young's Modulus from Bending Test and stress wave velocity measurement

There is some material testing devices to find Young's modulus. In this chapter, we explained three devices and their handling methods: one is Tapping-Tone Technique, stress wave velocity test and the bending test.

There is Tapping-Tone Technique as one of the system to investigate Young's modulus. As shown in Fig 3.1, we tap on the end grain of timber, catch natural frequency of longitudinal vibration at other end and calculate fundamental frequency by fast fourier transform analyzer. Young's modulus is calculated from fundamental frequency and density. Therefore, it is needed to bring down member and to tap cross section. In short, it is difficult to use for

existing buildings which are in use.

The instrument Fakopp is used to conduct the stresswave velocity test, this instrument estimates Young's modulus of standing trees from stress wave velocity. Two sharp pins are driven into tree two meter apart as shown in Fig 3.2. Here, each pin is the input and output sensors, the pins are leaned at 45 degrees facing: the manual recommend this angle. We tap the input pin on the head, and the output pin receive stress wave.

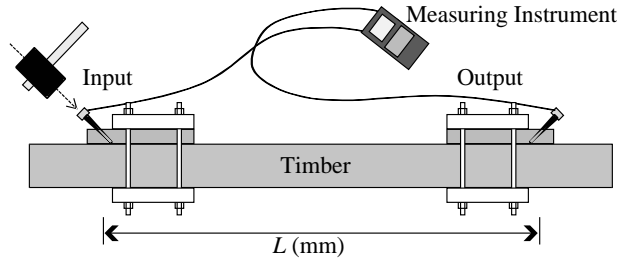


Figure 3.5 Improved stress wave velocity measurement by Fakopp

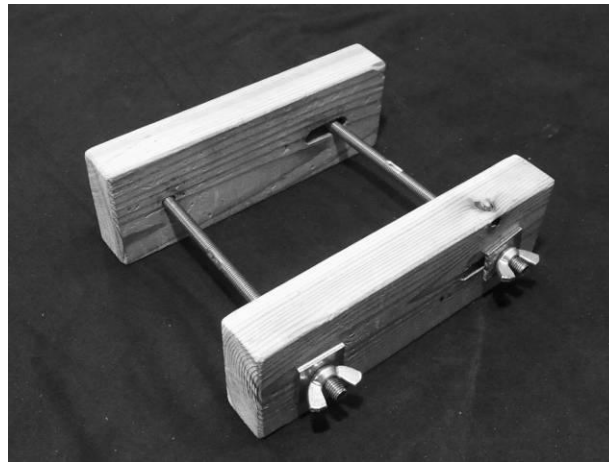


Figure 3.6 Simple device made of wooden plates and bolts to tighten supports

Stress wave velocity is made corrective by

$$V_f = L / (T_f - \alpha) \quad ()$$

where L = length among pins, T_f = measured propagation time of stress wave, $\alpha = 7$ (recommended corrective factor which depend on the instrument) and V_f = corrected stress wave velocity. Young's modulus can be calculated by

$$E_f = \rho \cdot V_f^2 \quad ()$$

where E_f = Young's modulus and ρ = density.

But this test is with a slight wound by pins and difficult to use for existing buildings too.

There is also three-point bending test for timbers as shown in Fig 3.3. The flexural strength and flexural stiffness of members are calculated. But this is destructive test, and can't be applied to existing structures.

3.3 Relation between density and young's modulus

In this chapter, we perform the material tests referred to chapter 2 and report on the results of the tests.

We found Young's modulus from each test with a regression line as shown in Fig 3.4. Here, E indicates Young's modulus from bending test, E_t is one from Tapping-Tone Technique, and R is a correlation coefficient. Assuming that Young's modulus E of bending test is standard, E is calculated by

$$E = E_t / 1.18 + 0.805 \quad (3)$$

It's said that Young's modulus from Tapping-tone technique and Improved stress wave velocity measurement by Fakopp are correspond roughly with one from bending test. Therefore, we'll improve the stress wave velocity measurement by Fakopp to apply in existing structures in next chapter.

3.4 Improved stress wave velocity measurement

We improve the method of using Fakopp on existing wooden structures as shown in Fig 3.5. Supports made of wood plate are put on the point drive in pins. The member and the supports are tightened with the simple device made of plates, steel bars and wing nuts. The device is shown in Fig 3.6. Being careful not to touch member, two pins of Fakopp are drove in supports by hammer to the surface of member.

Here, wood plate of device is cedar and the size is $105 \times 45 \times 300$ (mm). And steel bars of device have a diameter 12mm and coarse thread all length.

3.4.1 Inspection test

We perform some experiment posed parameters such as the length among pins L (mm), the way to hit the head of pins such as height dropped hammer head h (mm), the driven angle of pins θ (rad), the length of support l (mm), wooden species of support, the driven depth of pins d (mm), the strength tightened nuts of device or difference between standing and lying as shown in Fig 3.7.

We conduct tests for 4 specimens. To study effects by driven angle of pins, we use cypress column which section is 140×140 mm. To study difference by density, we choose 3 timbers are cedar, zelkova and oak. Based on Recommendations for Loads on Buildings in AIJ [8], the

densities are $0.38 \times 103(\text{kg/m}^3)$ as cedar, $0.62 \times 103(\text{kg/m}^3)$ as zelkova and $0.90 \times 103(\text{kg/m}^3)$ as oak. The specimens are the column which section is $120 \times 120\text{mm}$.

And we use 9 supports. The differences among the supports are the kind of timbers and/or length l (mm) of supports. The kinds of timbers are cedar, zelkova and oak. The supports are rectangular parallelepiped: thick is 30mm, width is 120mm and length l is 3 types such as 67.5, 150 and 180mm. The length direction of the support is parallel to wood fiber of supports, and the length direction of the supports is also set up to parallel with the fiber direction of specimen.

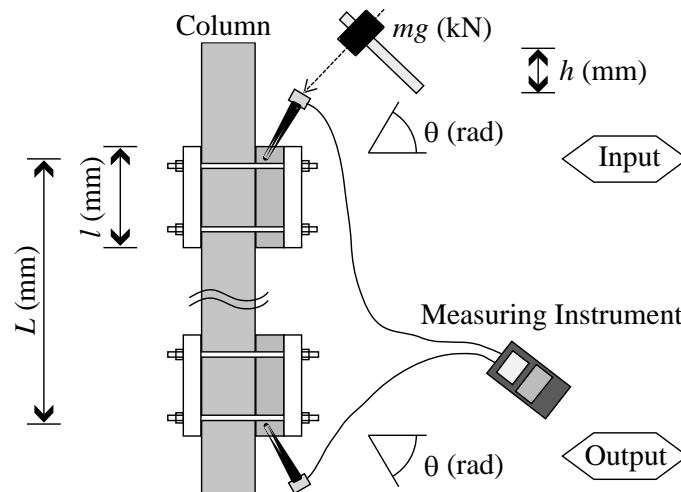


Figure 3.7 Parameter of improved stress wave velocity measurement

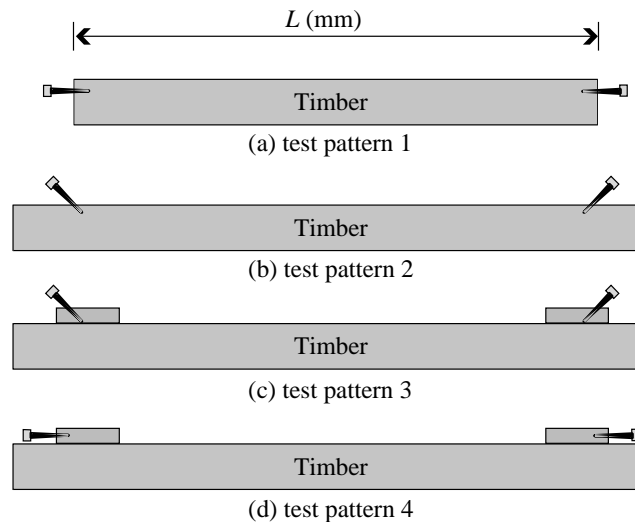


Figure 3.8 Test pattern using Fakopp: (a), (b) without support, (c), (d) with support

Tests are conducted with 4 patterns as shown in Fig 3.8. In test pattern 1, the pins are driven into specimen's section to parallel with fiber direction. Test pattern 2 is traditional way. In test pattern 3, improved system, the pins are driven into supports with angle. In test pattern 4, improved system, the pins are driven into support's section to parallel with fiber direction.

In one test, we tap 10 times under the same condition. And the figures which are over 3

percent away from the average are removed and tap again until 10 data are collected. And test scene in laboratory to use Fakopp and scene of investigation at existing structures are shown in Fig 3.9.



Figure 3.9 Picture of scene to apply the Improved stress wave velocity measurement by Fakopp: (left) tests in laboratory, (right) investigation on existing structures

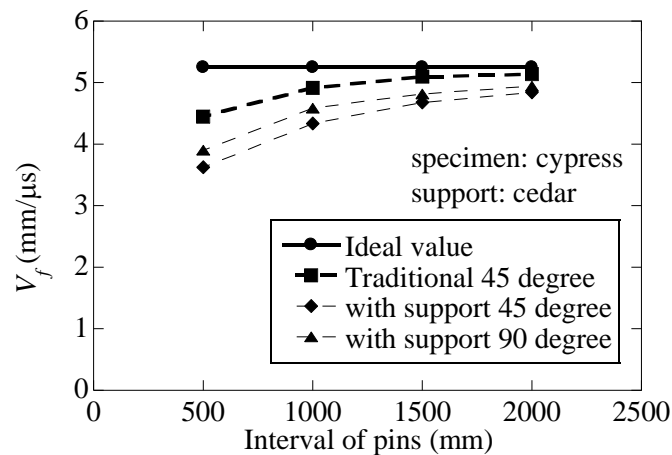


Figure 3.10 Effects by driven angle of pins

3.4.2 Driven angle of pins

Here, the value measured by using traditional way in the case of leaned pins forward 90 degrees (test pattern 1) and 2000mm interval pins is ideal value. Using cypress specimen, comparison of the ideal value with the values in each case is as shown in Fig 3.10.

In case pins are driven to 45 degree, correcting usual method, the value by improved way (test pattern 3) is recorded further from more ideal value than one by traditional way (test pattern 2). As to degree pins leaned, the value in 45 degree (test pattern 3) is further from ideal value than one is 90 degrees (test pattern 4). So, in this paper, we focus and develop about test pattern 4.

Moreover, with the length among pins shortening, measured values are further from ideal value in all cases.

3.4.3 Length and wooden species of support

In this paragraph, we study the difference that caused by the length of the support and the wooden species used as the support.

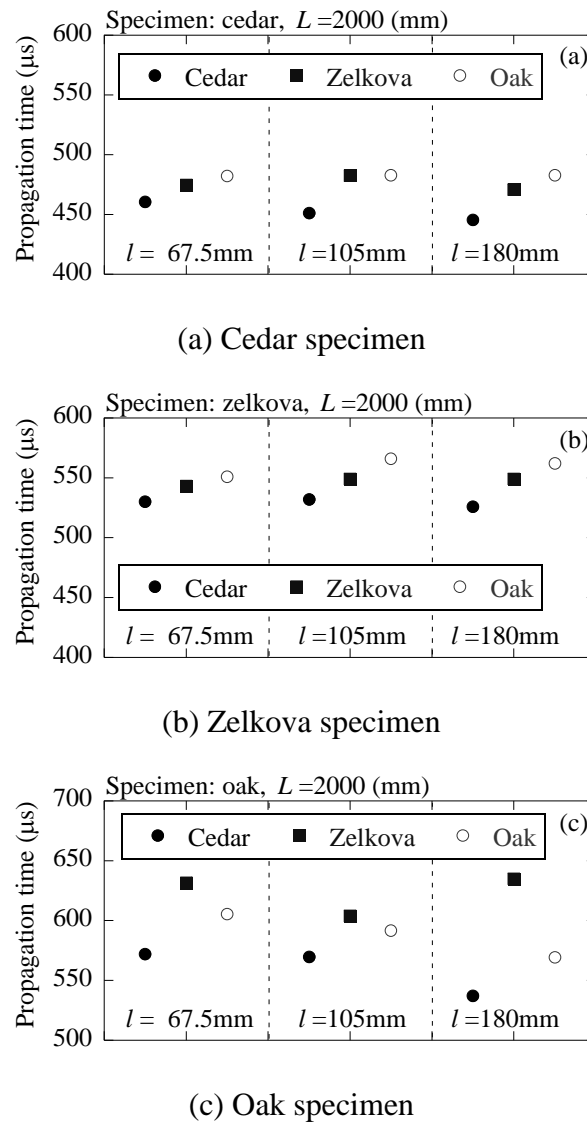


Figure 3.11 Comparison of length and wooden species of support

Figure 3.11 shows the results of propagation time when support length is changed and when species combination of specimens and supports is changed. Here, we use cedar, zelkova and oak specimens and driven angle is 90 degree (test pattern 4).

In the case of cedar and zelkova specimen, propagation times are resulted even by all size and all species of supports as shown in Fig 3.11 (a), (b). On the other hands, in the case of oak specimen, propagation time is uneven by length $l = 67.5$ and 180 (mm) as shown in Fig 3.11 (c).

It is easy for the supports which length 67.5(mm) to be broken by pins. And it is easy for oak to transform and to be broken by seasoning. So, in this system, zelkava is used as support.

3.4.4 Way to hit head of pins and strength tighten nuts

In this paragraph, we study the difference caused by the way to hit the head of the pins such as specifications of using hammer and strength to hit the head and the difference caused by the strength to tightened wing nuts of the device. Here, we conduct test pattern 4.

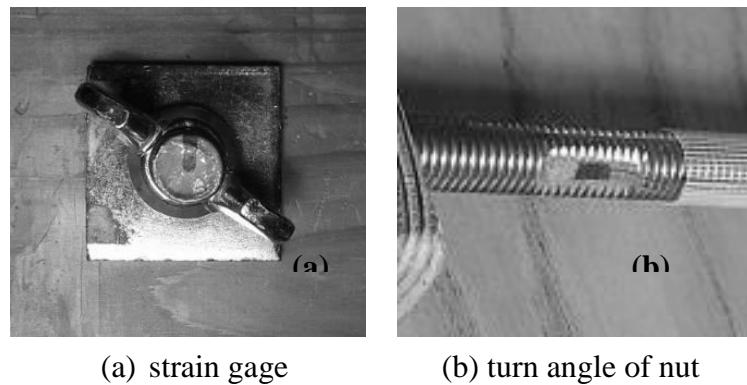


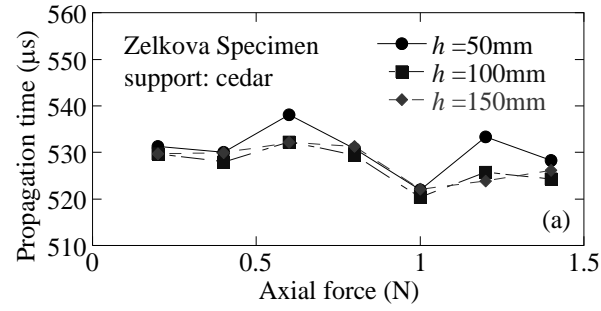
Figure 3.12 Measurement method

First, to measure the strength tightening nuts, two strain gages are put facing on the steel bar as shown in Fig 3.12 (a), and calculated axial force. Next, to visualize the relation between axial force and rotation angle of wing nuts after touching wood plate and nuts, initial position of wing nuts are marked on section of steel bolts by marker as shown in Fig 3.12 (b). Finally, to decide tapping strength for stable measurement, free fall height dropped hammer head is changed 50, 100 and 150mm. Here, we use test hammer whose head's weight is 100g.

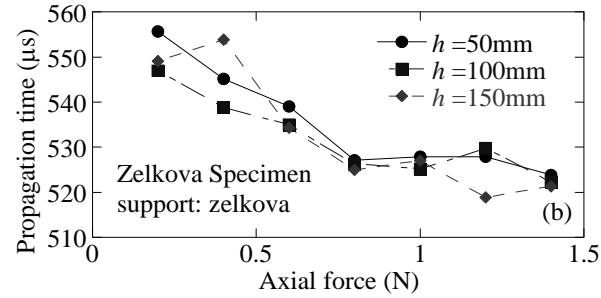
Figure 3.13 shows the relation between strength of tightening nuts and propagation time of stress wave by all support using. Here, the result about only zelkova specimen is shown, but similar results are about other specimen. And Table 1 is said the relation between axial force owed steel bar and rotation angle of wing nuts. Here, rotation angle of wing nuts indicated the rotation angle from when the wing nuts touch the wooden plate of device completely.

The propagation time is stable in all species of support when the strength of tightened nuts is over 0.8N of axial force. As shown in Table 3.1, it is good that the wing nuts are rotated from 100 to 150 degrees from when they touch the wooden plate completely.

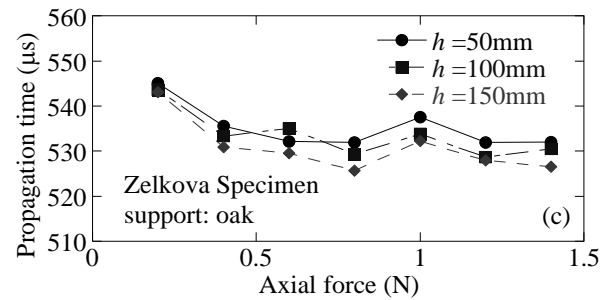
Finally, to decide tapping strength for measurement, free fall height of the dropped hammer head is changed. Using test hammer which head has 100g heavy, the free fall height of the dropped hammer head is 50mm enough to measure stable figures.



(a) Cedar as support



(b) Zelkova as support



(c) Oak as support

Figure 3.13 Relation between strength tightened nuts and time of transmission stress wave on zelkova specimen

Table.3.1 Margin settings

axial force [N]	0.4	0.6	0.8	1.0	1.2	1.4
rotation angle	~ 100 degree		100 ~ 150 degree			
measurement	unstable		stable			

3.4.5 Driven depth of pins

In this paragraph, we study the difference caused by the driven depth of the pins.

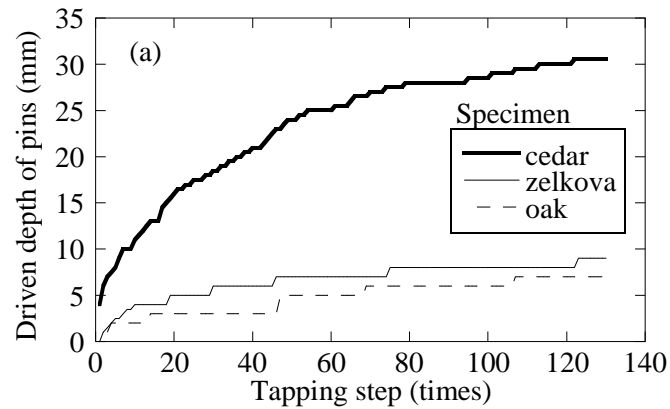
The change of driven depth of pins increasing tapping step is as shown in Fig 3.14 (a). The change of propagation time as the driven depth of the pins is as shown in Fig 3.14 (b). In this figure, the result of cedar specimen (length among pins $L = 500\text{mm}$), zelkova specimen ($L =$

2,500mm) and oak specimen ($L = 2500\text{mm}$) by test pattern 1 is shown.

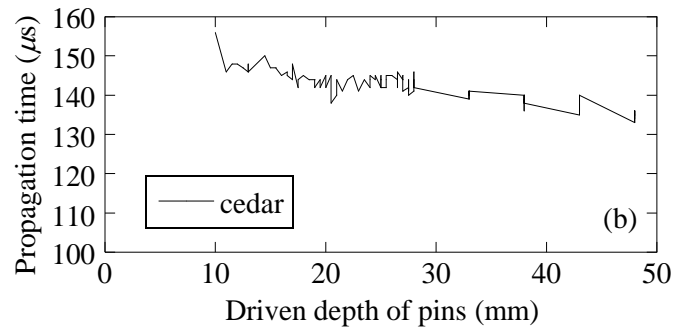
As to cedar specimen, as the tapping step increase, the driven depth of pins approach 30mm asymptotically. Following that, propagation time is stable.

In the same way, in the case of zelkova and oak specimen, when pins are driven each 7 mm and 5 mm in depth, propagation time is stable.

So, in this way, pins are driven 30mm in depth based on result of cedar specimen.



(a) Driven depth of pins as tapping step



(b) Propagation time as driven depth of pins

Figure 3.14 Driven depth of the pins which is measured stable

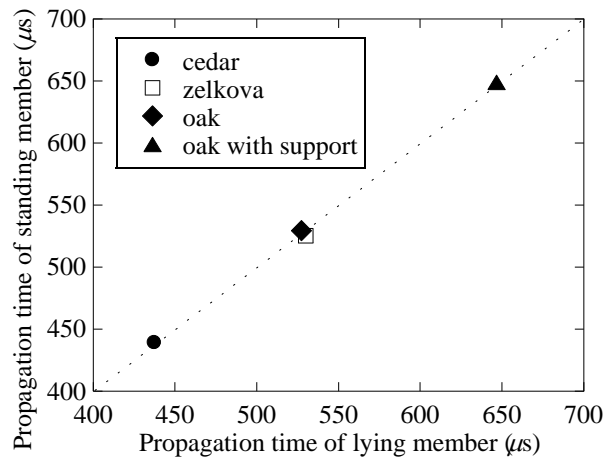


Figure 3.15 Comparison of propagation time between standing and lying member

3.4.6 Lying and standing members

In this paragraph, we study the difference caused by the position of the members which are standing and lying.

The comparison of propagation time between standing and lying members is as shown in Fig 3.15. In case without support (test pattern 2), on each specimens, propagation time of standing member is even with one of a lying member. On the other hand, for example, as to oak specimen with the device (test pattern 4), it is said that the propagation time doesn't depend on the position of standing or lying.

Therefore, it is evident that we can apply improved device on the columns of existing structures.

3.4.7 Intervals of pins

In this paragraph, we study about difference caused the intervals of the pins.

The relation between interval of pins and propagation time about cedar, zelkova and oak specimens is shown in Fig 3.16. Here, supports are changed as the kind of wood and interval of pins are $L = 500, 1000, 1500, 2000\text{mm}$.

It is obvious that the relation between the interval of pins and propagation time is linear on each specimen. And, whatever support is used, on every interval length, the difference among species of specimen is roughly equal.

3.5 Uniform directions and revised formula

In this chapter, we will decide the directions of using the improved device and investigate two calculated methods based on chapter 4. Here, two calculated methods are proposed to separate enough long members and about short members. At the same time, comparison between the values from improved stress wave velocity measurement by Fakopp and the ones from Tapping-Tone Technique is conducted.

3.5.1 Directions of use

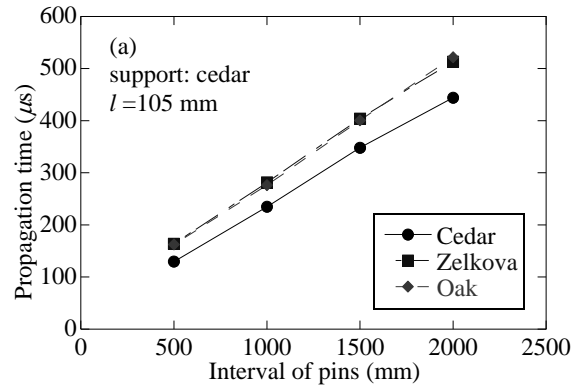
Based on the result in chapter 4, the directions of use are decided on.

First, method of setting up the device is following:

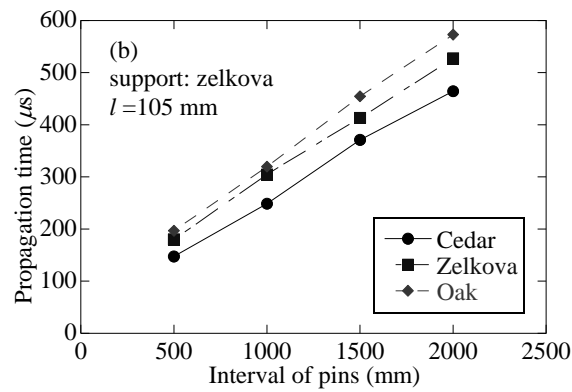
- (1) The fibre direction of the supports is parallel to one of object to measure.
- (2) Zelkova support which length is 105.0mm is used.
- (3) Turning angle of nuts is from 100 to 150 degrees when nuts touch wood plate of device.
- (4) The pins are driven 30mm in depth.
- (5) Next, tapping technique is following:
- (6) Using test hammer whose head is 100g heavy, the head of hammer has a free fall from

50mm height.

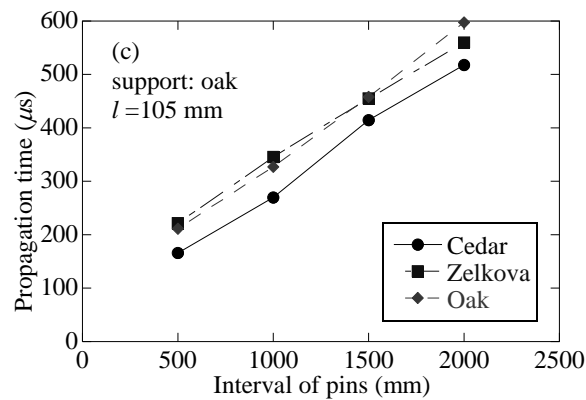
Investigation is conducted along two routes in Fig 3.17. Phase I and II are explained in Chapter 5.2 and 5.3.



(a) Cedar



(b) Zelkova,



(c) Oak

Figure 3.16 Relation between the interval of pins and propagation time about 3 specimens with support made of 3 specimens

Table 3.2 Material quality

member	density (t/m ³)	water content	Et from Tapping-Tone Technique
cedar	0.406	10.0 %	9.10 (kN/mm ²)
zelkova	0.720	22.6 %	11.19 (kN/mm ²)
oak	1.033	23.2 %	14.64 (kN/mm ²)

Is the column long enough to measure more than two point ?

Yes

PHASE II

No

PHASE I

New corrective factor
is proposed.

Figure 3.17 Flowing of investigation on one column

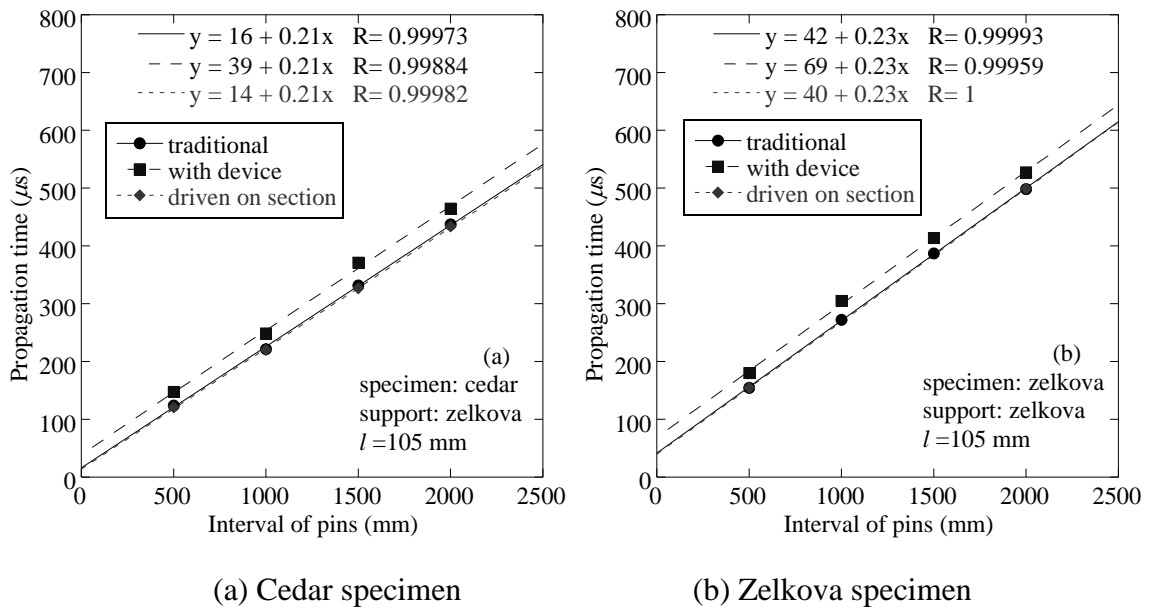


Figure 3.18 Relation between interval of pins and propagation time with regression line on 2 specimens

3.5.2 New corrective factor on short members (phase i)

In this paragraph, we propose the new corrective factor $\bar{\alpha}$. This factor is considered according to some effects for instance, the use of some devices and so on. With this correction, measured value is nearly equal to ideal value in the case of the length among pins below 2000 (mm).

The relation between interval of pins and propagation time on cedar and zelkova specimens is shown in Fig 3.18. Here, the data which is conduct in the traditional method (test pattern 2),

method of using improved device (test pattern 4) and method of driving the center of section (test pattern 1) are indicated with regression lines. It is found that each data is shown in a straight line and all regression lines are nearly parallel. And the regression line from test pattern 1 and one from test pattern 2 are laid to overlap each other. These intercepts can be called corrective factor $\bar{\alpha}$ which controls the results.

The intercepts depend on species of specimen and whether to use a device or not as shown in Table 3.3. And the relation between density and intercept is indicated in Fig 3.19. The density, the intercept of test pattern 1, 4 and growth rate of these increases as curving when improved devices are used. We must conduct tests for many kinds of timbers to decide this function. But, in the case of cedar, zelkova and oak, the corrective factor $\bar{\alpha}$ is given as Table 3.3.

Table 3.3 Intercepts as corrective factor $\bar{\alpha}$

	test pattern 1	test pattern 2	test pattern 4
cedar	14 (s)	16 (s)	39 (s)
zelkova	40 (s)	42 (s)	69 (s)
oak	46 (s)	-	76 (s)

Table 3.4 Combination of test results and the value L_r

L (mm)	500	1000	1500	2000
500	<div style="position: relative; height: 100%; width: 100%; border: 1px solid black;"> <div style="position: absolute; top: 0; left: 0; right: 0; bottom: 0; border-left: 1px solid black; border-right: 1px solid black; border-bottom: 1px solid black;"></div> </div>	$L_r=500$	L_r	L_r
1000			$L_r=500$	$L_r=1000$
1500		pair 4		$L_r=500$
2000		pair 2	pair 1	

3.5.3 Propagation time on enough long members (phase ii)

We study another calculating way of Young's modulus because of linear relation between interval of pins and propagation time as shown in Fig 3.17. Here, we propose the calculating methods on enough long members.

The method of finding Young's modulus is following:

The measurements are conducted more than twice, which are changed the length among pins L .

Finding the reminder of propagation time among the datum which differ in L , reminder

among L (called L_r) divided by the value makes stress wave velocity. In short, it can cancel error from the instrument and support, and corrective factor $\alpha=0$.

For example, we'll verify the above based on Fig 3.16. Young's modulus is found using material quality as shown in Table 3.2.

First, according to data combinations as shown in Table 3.4, the reminders of propagation time among the data which differ in L are found. Here, the value L_r and the number of the combination 'pairs' is indicated in the table. Next, each stress wave velocity is found by eq.1 on $\alpha=0$. Finally, each Young's modulus is found by eq.2. Comparison of Young's modulus between improved stress wave velocity measurement by Fakopp and Tapping-Tone Technique is shown in Fig 3.20. Here, value from Tapping-Tone Technique is modified by eq.3. It seems that they are roughly matching.

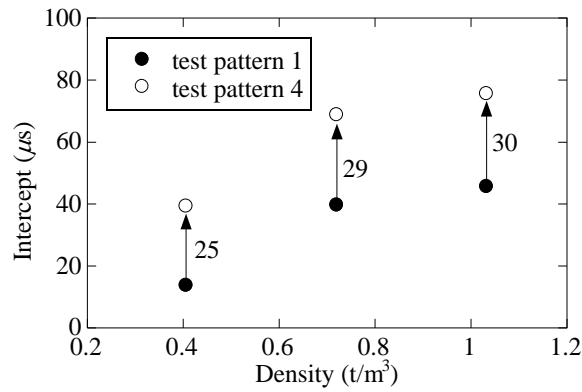


Figure 3.19 Relation between density and intercept

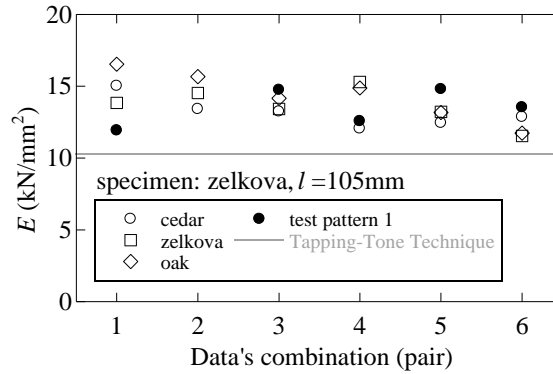


Figure 3.20 Comparison between Young's modulus from Tapping-tone Technique and Improved stress wave velocity measurement by Fakopp using combination in Table 3.3

3.6 Proposed estimation of timber grade

In this chapter, we conduct improved stress wave velocity measurement test, and verify the relation between Young's modulus and strength from bending test, and propose estimation method of timber grade with consideration of heterogeneity of density.

3.6.1 Young's modulus and strength under stress wave velocity measurement test

We conduct improved stress wave velocity measurement test, Tapping-Tone Technique and bending test while using 11 timber specimens as shown in Table 3.5. Timber type of No.1-6 is cypress whose grade is E110 and one of No.7-11 is cedar whose grade is E70. Section of No.1-6 is $120 \times 120\text{mm}$ and one of No.7-11 is $105 \times 105\text{mm}$. Young's modulus from stress wave velocity measurement test, Tapping-Tone Technique (FFT) and bending test and strength from bending test are indicated in the table.

JAS established by MAFF (Ministry of Agriculture, Forestry and Fisheries) distinguishes timber grades. The relation between timber type and grade is indicated in Table 3.6.

Table 3.5 Details and test results of Specimen

Spec.	Type	Grade	Section (mm)	Density (t/m^3)	Dry (%)	Young's Modulus (kN/mm^2)			Strength (N/mm^2)
						Stress Wave	FFT	Bending test	
01	cypress	E110	150x150	0.51	18.2	13.59	10.49	9.16	51.87
02			120x120	0.50	17.5	10.32	8.69	7.78	42.98
03				0.47	15.0	10.49	9.18	8.28	55.99
04				0.53	19.5	16.39	12.30	9.41	57.3
05				0.52	17.0	13.07	10.27	8.34	60.9
06				0.52	18.8	13.10	11.21	9.04	58.5
07	cedar	E70	105x105	0.40	13.8	9.20	8.12	6.99	33.50
08				0.46	16.5	9.51	x	5.44	42.22
09				0.39	13.7	9.38	x	6.65	38.68
10				0.45	11.7	10.14	x	6.53	42.22
11				0.42	12.7	9.68	x	6.40	40.15

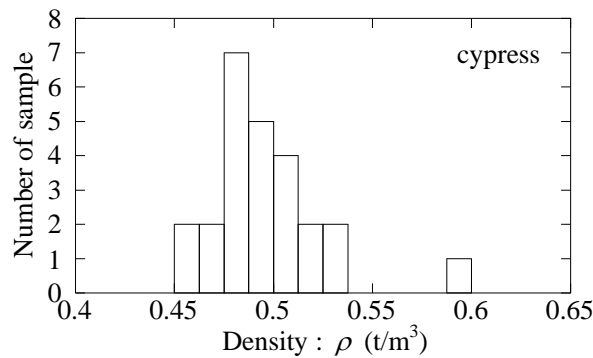
According to the value of standard strength of wood by unaided viewing from Code.1452 of Ministry of Construction of Japan[18], the results from tests distinguish from the recommended value, which suggests that the unreliability of unaided viewing inspection method in the condition of field survey on existing buildings, and improved stress wave velocity measurement is expected to increase the accuracy of the estimation of the timber grade for existing buildings.

3.6.2 Heterogeneity of density

When estimating Young's modulus, density is needed. But it is difficult to grasp material density in existing buildings. Moreover, if we distinguish types of timber, the density is heterogeneity. So we examine heterogeneity of density by using 25 samples of cypress timber.

Density distribution of cypress is shown in Fig 3.21. Density of cypress is 0.43 defined by AIJ (Architectural Institute of Japan 2004). This is the value measured from the material in air-dry condition where water content is about 15%. So here, compared with the value defined by AIJ, the result of density is revised which is equal to water content that is 15%.

The average of density is higher than the value defined by AIJ. Standard deviation is $0.028(t/m^3)$. So we consider heterogeneity of density as $0.028(t/m^3)$. And fluctuations are in the defined value. For example, Young's modulus of cypress has an error of less than 7 %.



Density defined by AIJ (t/m^3)		0.43
Number of sample : n		25
Density	average : ρ_{ave}	0.495
	standard deviation	0.028
	maximum : ρ_{max}	0.594
	minimum : ρ_{min}	0.452

Figure 3.21 Density distribution of cypress

3.6.3 Estimation of timber grade

JAS established by MAFF (Ministry of Agriculture, Forestry and Fisheries) describes timber grades. The relation between timber type and grade is indicated in Table 3.6. The grade is said the lower limit of Young's modulus, and together with it, the lower limit of strength is also decided. As to conifer, the grade is decided. On the other hand, the grade of hard wood isn't decided but specified material strength and specified Young's modulus are indicated in the table.

Table 3.6 Relation between grade and characteristics of each kind of timber

Group	Type	Characteristics	Notation	Grade					
				E50	E70	E90	E110	E130	E150
Conifer	cedar	Strength	F_b (N/mm ²)	24.0	29.4	34.8	40.8	46.2	51.6
		Young's modulus	E_0 (kN/mm ²)	4.9	6.9	8.8	10.8	12.7	14.7
	cypress	Strength	F_b (N/mm ²)	13.8	22.2	30.6	38.4	46.8	55.2
		Young's modulus	E_0 (kN/mm ²)	4.9	6.9	8.8	10.8	12.7	14.7
Hard wood	zelkova	Strength	F_b (N/mm ²)	29.4 (specified material strength)					
		Young's modulus	E_0 (kN/mm ²)	8.0 (specified Young's modulus)					

The values of Young's modulus of bending test, E_{b1} is calculated by following equation:

$$E_{b1} = (\rho - \rho_0) V_f^2$$

ρ_0 is $0.028(t/m^3)$, which is the deviation value of the standard density referred from the previous literature.

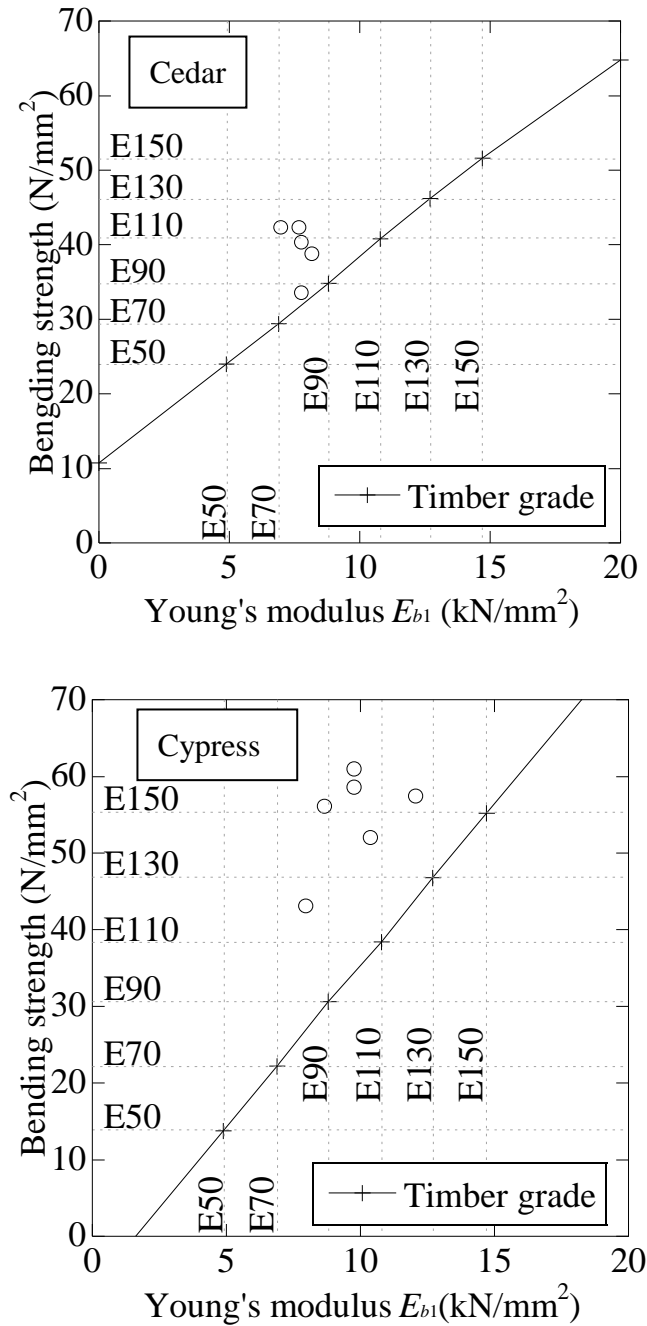


Figure 3.22 Young's modulus E_{b1} with range of timber grade

As mentioned above, it is found that Young's modulus of timber is estimated precisely under improved stress wave velocity measurement, and provided timber grade is specified under Young's modulus, and strength can be estimated.

3.7 Estimation of the bending strength of column

The breaking of column sometimes directly leads the collapse of the house, thus, it is very important to estimate the bending strength of the columns for the seismic diagnosis. In addition, considering the deviation of the destroying mode of hanging wall frames, and retrofit design based on seismic diagnosis, the deviation need to be examined. Here we use the Improved stress wave velocity measurement by Fakopp to estimate the bending strength of the columns.

The bending strength of column represents the ability of column to resist deformation of load, and the usually the bending test is employed to examine the strength of material at its moment of fracture. The value of F_b is estimated based on the regression analysis of previous experiment data on cedar and cypress of Hayashi Laboratory. Table 3.8-10 shows the resources of the data for the analysis. The procedure of estimation is explained as follows:

- (1) Figure 3.26 shows the relation of the estimated value of Young's modulus by bending test (E_{b2}) and by Improved stress wave velocity measurement by Fakopp (E_f).

Cedar: $E_{b2}=0.68E_f$, Cypress: $E_{b2}=0.75E_f$.

- (2) Figure 3.27 shows the relation of the bending strength (F_b) and Young's modulus from bending test (E_{b2}), and defined reference intensity and the 95% confidence interval. Confidence interval indicates the reliability of estimation in statistics, and it generates a lower and upper limit for the mean. 95% confidence interval is widely employed in the strength test of wood material, and the reference strength of the timber material is defined as the lower limit of the 95% of the 75% confidence level [12]. Figure 3.28 shows the derived reference strength and the reference strength for design according to the timber grades.

Cedar: $F_b = 16.86 + 3.1 E_{b2}$; Cypress: $F_b = 19.75 + 3.77 E_{b2}$

- (3) Figure 3.29 shows the relation of bending strength (F_b) and the Young's modulus by Fakopp (E_f).

Cedar: $F_b = 16.86 + 3.1(0.68E_f)$; Cypress: $F_b = 19.75 + 3.77(0.75E_f)$

Table 3.7 Number of objects and availability of Fakopp data

Item	Number		FAKOPP data
	Cedar	Cypress	
Kyomachiya	7	14	Available
Kyomachiya	-	10	
Total	7	24	-

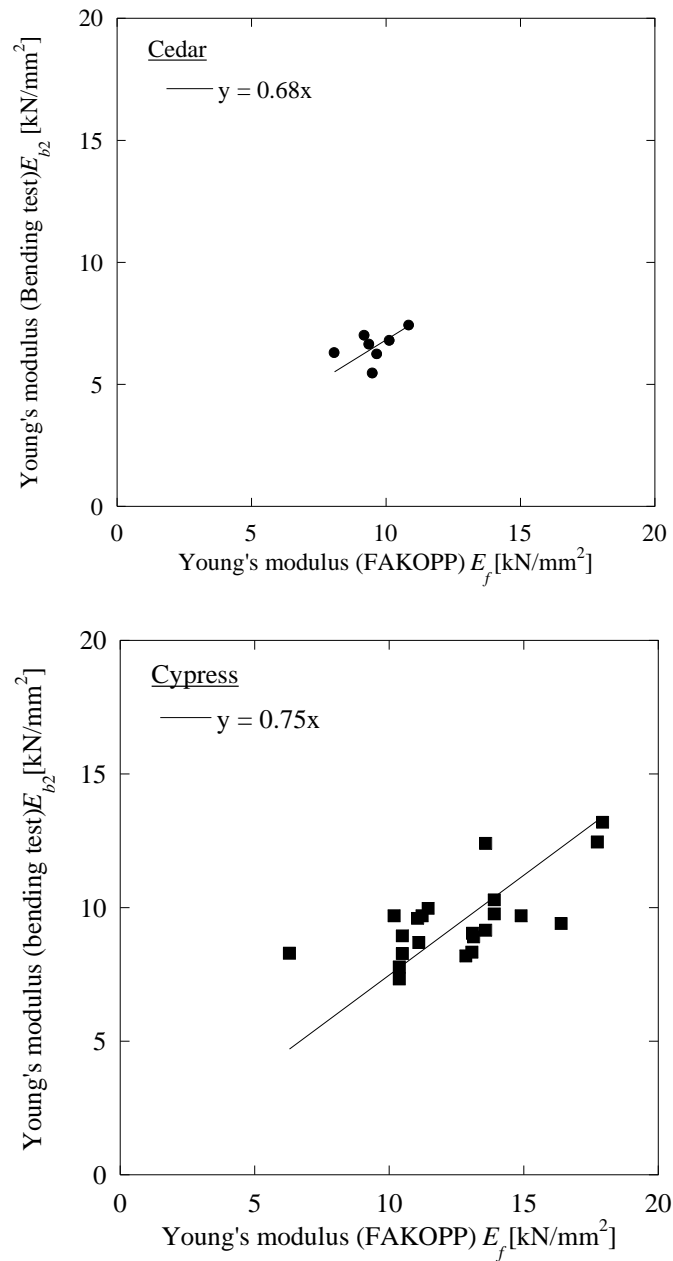


Figure 3.26 Relationships between E_{b2} and E_f

Table 3.8 Number of objects and availability of Fakopp data

Item	Number		FAKOPP data
	Cedar	Cypress	
Frame	58	-	-
2010 shaking table experiment	28	-	
Kyomachiya	5	6	Available
Kyomachiya	-	10	
Total	91	16	-

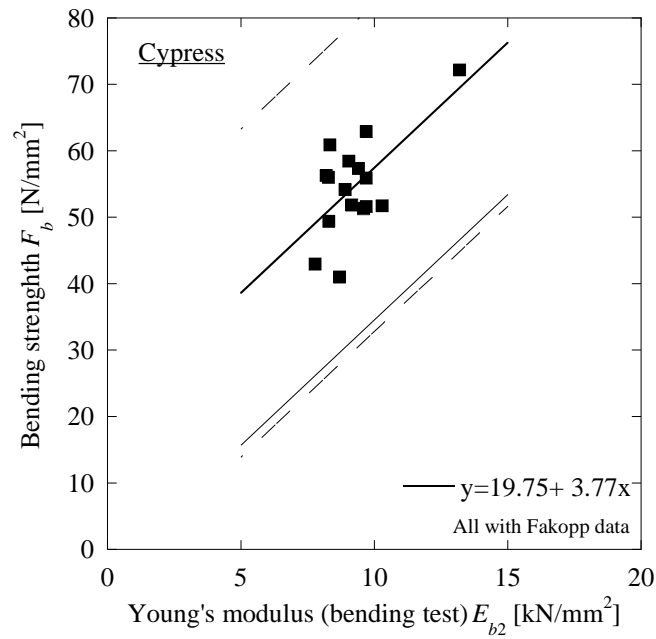
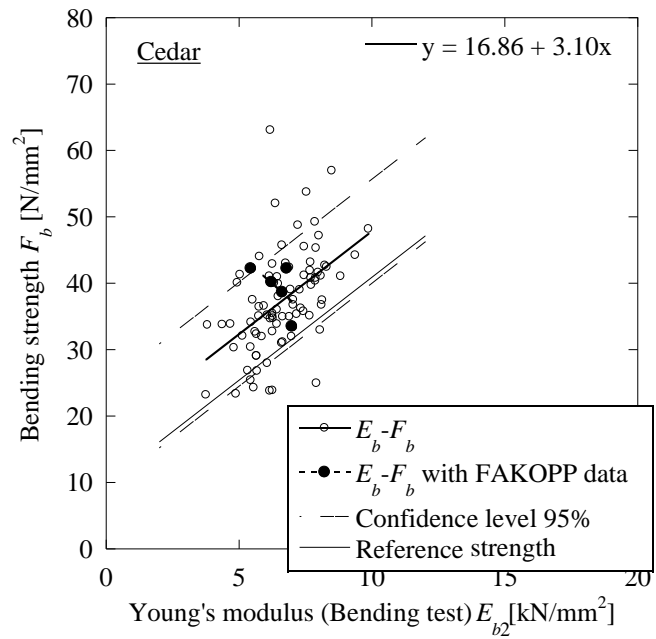


Figure 3.27 Relationships between F_b and E_{b2}

Table 3.9 Number of objects and availability of Fakopp data

Item	Number		FAKOPP data
	Cedar	Cypress	
Frame	58	-	-
2010 shaking table experiment	28	-	
Kyomachiya	5	6	Available
Kyomachiya	-	10	
Total	91	16	-

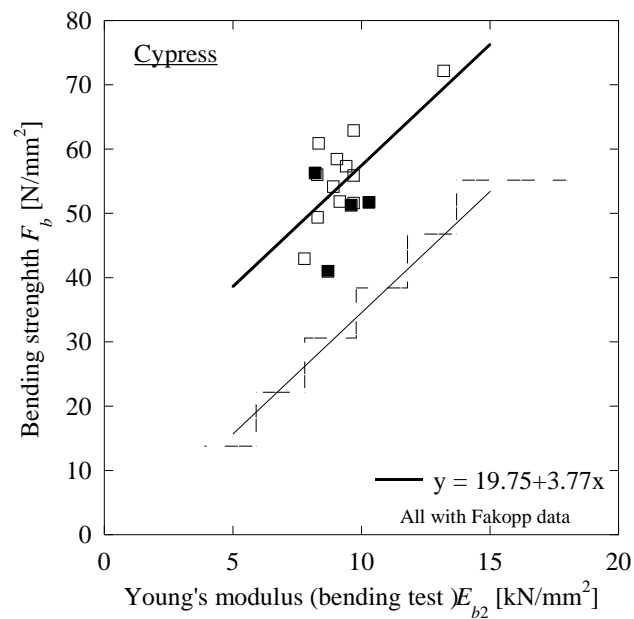
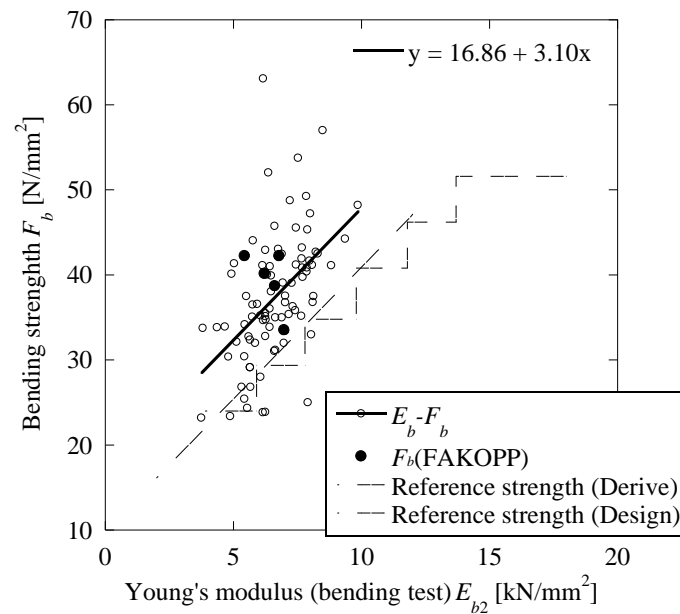


Figure 3.28 Relationships between F_b and E_{b2}

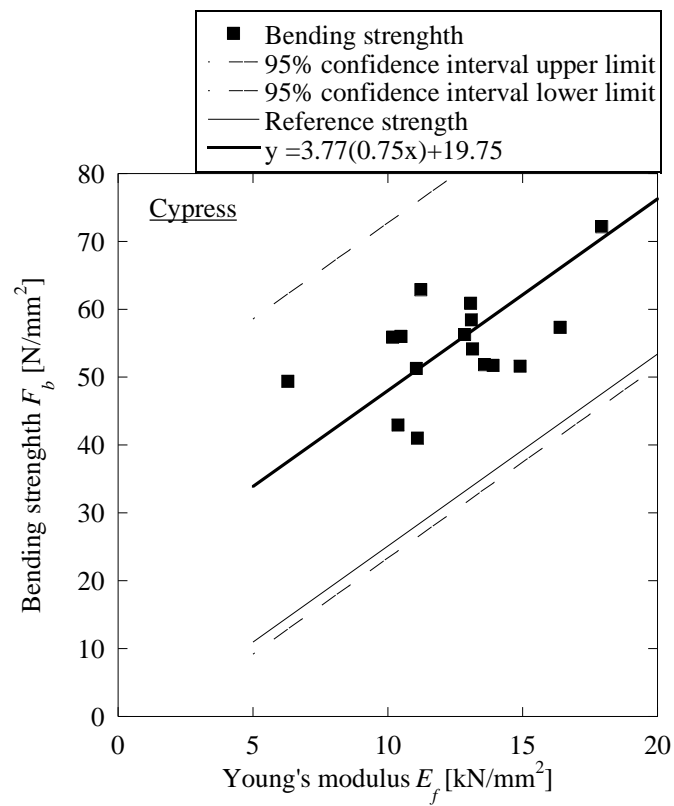
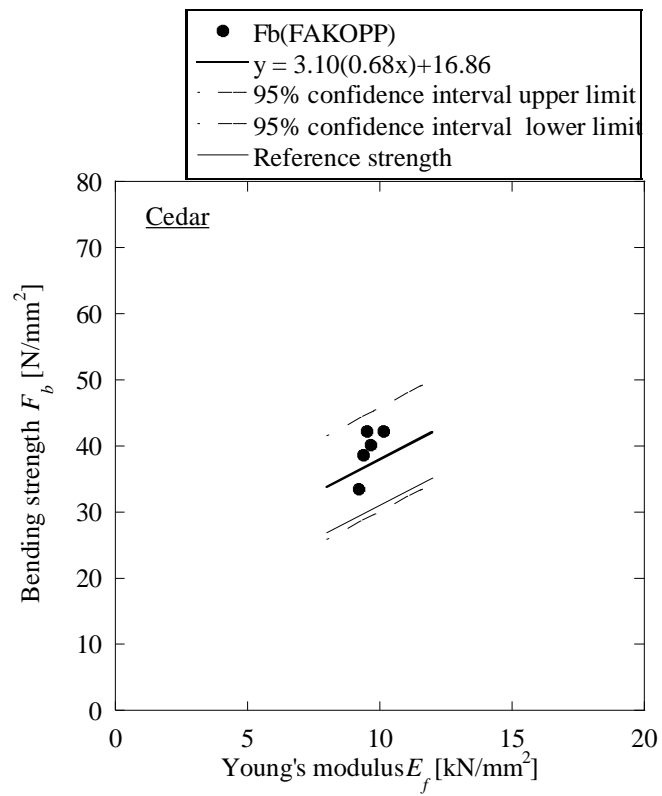


Figure 3.29 Relationships between F_b and E_f

3.8 Demonstration under existing wooden houses

We investigate traditional wooden houses in some important districts of groups of historic buildings such as Kyoto city, Yuasa town, Hashidate town, Seki in Mie prefecture, Gojo in Nara prefecture and Happo in Akita prefecture as shown in Fig 3.23. We examine some columns by stress wave velocity measurement and timber grades are specified.



(a) Kyoto (Kyoto)



(b) Yuasa (Wakayama)



(c) Hashidate (Ishikawa)



(d) Happo (Akita)



(e) Seki (Mie)



(f) Gojo (Nara)

Figure 3.23 Appearance of houses in each district

Table 3.10 Examined columns

Districts	No. of column	Species	Density (t/m ³)	Dimension (mm)	Moisture content (%)	E_{b1} (kN/mm ²)	Grade	E_{b2} (kN/mm ²)	F_b (N/mm ²)
Kyoto	c01	Cypress	0.430	115	17.3	8.9	E90	7.4	47.5
	c02			115	9.3	6.0	E50	5.0	38.4
	c03			115	12.5	8.3	E70	6.8	45.5
	c04			115	9.2	6.0	E50	5.0	38.4
Yuasa	c05	Zelkova	0.620	115	19.5	15.4	-	-	-
	c06			195	21.3	10.7	-	-	-
Hashitate	c07			120	-	14.5	-	-	-
	c08			100	-	10.6	-	-	-
Happo	c09	Cedar	0.380	150	-	9.2	E90	7.0	38.6
	c10	Zelkova	0.620	270	25.0	8.9	-	-	-
	c11			120	11.8	9.9	-	-	-
	c12			260	10.5	9.7	-	-	-
Seki	c13	Cedar	0.380	170	22.7	6.6	E50	5.0	32.5
	c14			120	17.0	7.0	E70	5.3	33.3
	c15			100	21.3	8.7	E90	6.6	37.3
	c16	Cypress	0.430	170	17.2	9.3	E90	7.7	48.6
	c17	Zelkova	0.620	220	22.5	17.6	-	-	-
	c18			170	18.7	21.4	-	-	-
	c19			215	15.0	9.5	-	-	-
	c20			120	18.8	12.1	-	-	-
Gojo	c21	Cedar	0.38	130	17.2	5.3	E50	3.8	28.7
	c22			130	16.2	6.0	E50	4.4	30.4
	c23			110	16.3	5.1	E50	3.7	28.3
	c24			110	17.7	4.7	E50?	3.4	27.5
	c25			125	16.2	2.0	E50?	1.4	21.3
	c26			145	20.8	5.2	E50	3.8	28.5
	c27	Cypress	0.41	150	22.2	4.9	E50	3.9	34.4
	c28			120	19.8	5.1	E50	4.1	35.1
	c29			115	19.0	4.5	E50?	3.6	33.5
	c30			105	21.8	5.1	E50	4.1	35.2
	c31			120	25.2	4.8	E50	3.8	34.2
	c32			125	16.5	5.0	E50	4.0	35.0
	c33			160	15.7	4.6	E50	3.7	33.6
	c34			150	16.7	4.6	E50	3.7	33.6
	c35	Torreya	0.47	150	11.0	3.1	-	-	-
	c36	Hemlock	0.47	105	16.8	3.9	-	-	-

3.8.1 Sites and objects

Some columns are selected to apply stress wave velocity measurement in Table 3.7. All columns in Kyoto are made of cypress. All columns in Yuasa, Hashidate and some in Happo are made of zelkova, and one kind of column in Happo is cedar. Here, the values defined by AIJ are used as reference for the density of these columns because their precise density has not been obtained. Section and water contents of column are actual measurements.

3.8.2 Test results

Examined results are shown in Table 3.7, Fig 3.24 and Fig 3.25. Table 3.7 shows Young's modulus, estimated grade of conifer and whether estimated Young's modulus of hard wood is over specified value or not. Here, considering heterogeneity of density, the lowest, centre and the highest values of Young's modulus are estimated by Eq.(1). Referred to the former chapter, density has $0.028 (t/m^3)$ fluctuations. Changed propagation time by distances between the two sensors under improved stress wave velocity measurement in all investigated districts is shown in Fig 3.24. Comparison of examination results of conifer with range of timber grade is shown in Fig 3.25 (a), and Comparison of examination results of hard wood with specified value is shown in Fig 3.25 (b)

In the test of conifer, the range of Young's modulus of cypress and cedar is estimated. And including the upper limit of Young's modulus, timber grade is decided between E60 to E90. In the test of hard wood, Young's modulus of zelkova is estimated and it is found that the estimated value is over specified value.

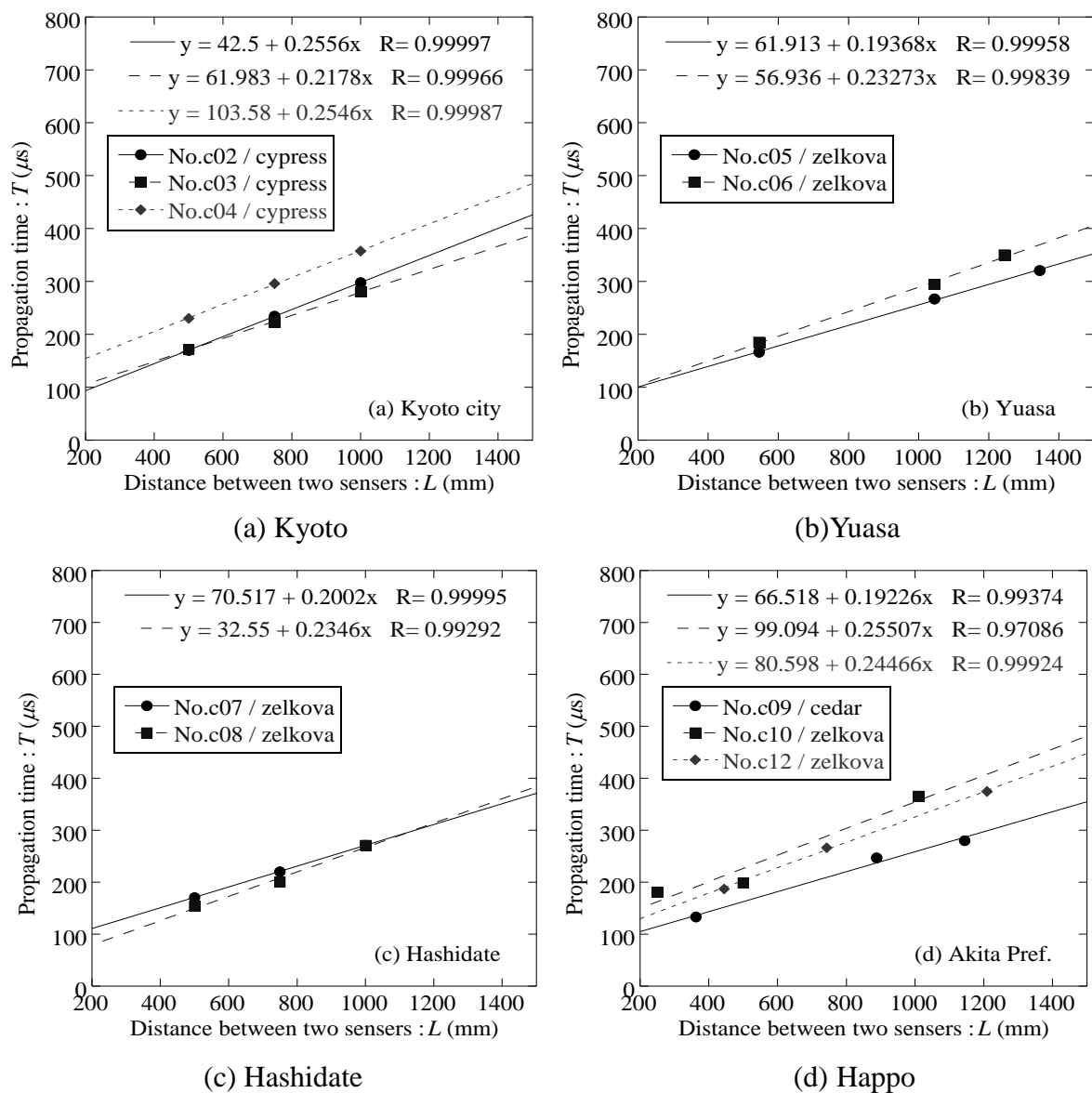


Figure 3.24 Result of investigation by improved stress wave velocity measurement

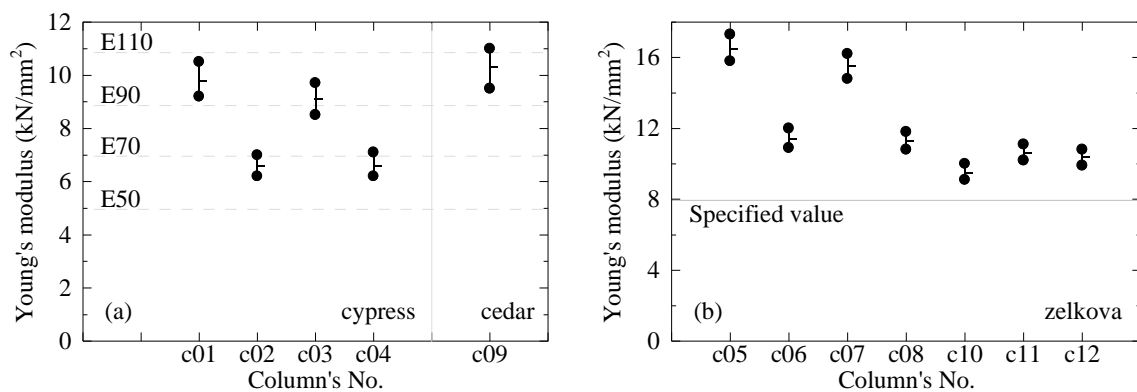


Figure 3.25 Comparison examination results with range of timber grade

3.9 Conclusion

We report the progress of our research projects on improvement of Young's modulus and bending strength measuring system for existing wooden structures by one of test device, Fakopp, based on stress wave velocity. The relation of the results from some material test methods such as Tapping-tone technique, Fakopp and bending test is studied. With improved measuring method of Young's modulus used, it can be measured precisely for existing structures. We also propose the method of determination of the timber grade of members and to verify the proposed method, and the timber grades of some columns in 6 investigated traditional districts are estimated. Finally based on the result of bending test and Fakopp test, the method of estimation of bending strength of column based on Fakopp test is proposed.

Major findings are listed as follows:

- (1) It is unreliable to apply unaided viewing inspection method in the condition of field survey on existing buildings, and improved stress wave velocity measurement is able to increase the accuracy of the estimation of the timber grade for existing buildings.
- (2) Some examination by improved stress wave measurement are conducted on cypress specimens, it is found that standard deviation under heterogeneity of density is $0.028 (t/m^3)$, and it is indicated that timber grade is estimated precise by improved method.
- (3) Based on the regression analysis of data from bending test and the improved non-destructive stress wave velocity measurement, the bending strength of column made of cedar or cypress could be estimated by the improved non-destructive stress wave velocity measurement for Young's modulus .

$$\text{Cedar: } F_b = 16.86 + 3.1(0.68E_f); \text{ Cypress: } F_b = 19.75 + 3.77(0.75E_f)$$

- (4) At Kyoto, Yuasa, Hashidate, Happa, Seki, and Gojo, we examined some columns of existing houses. Considering heterogeneity of density, the range of Young's modulus and grade are estimated, and the bending strength could also been indicated by the timber grade.

Admittedly, this research could be further extended on following aspects:

- (12) The regression analysis on the Zelkova for the bending strength estimation based on accumulation Young's modulus data by the improved testing method.
- (13) Collecting more data of Cypress and Cedar, to improve the accuracy of the regression analysis.

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Chapter 4 Questionnaire survey on habitation and disaster perception

4.1 Introduction

Traditional wooden buildings are extensively existing in Japan with various regional characteristics which highlight the Japanese traditional wisdom and constructing skills. As the significance of traditional wooden buildings and districts has been widely recognized and traditional districts have been regarded as an important category of cultural properties, many efforts of preservation have already been made in terms of legislation, policy making, various kinds of investigation and large number of houses and districts have been preserved [1].

According to the damage statistics of the 1995 Hyogo- Ken Nanbu Earthquake, most of fatalities due to the structural failure of old wooden buildings [2]. Thus it is important to estimate the vulnerability of built environment and the house- owners' interests of conducting seismic retrofit for their houses.

Table 4.1 Methods of traditional districts investigation

Inquiring survey	Interview with inhabitants
	Questionnaire survey
Structural properties survey	Architectural drawing
	Ambient vibration measurement of houses
	Interview with carpenters
	Status of houses (Decay, Inclination, Strength of column)
District survey	Ambient vibration measurement of ground
	Status of district

It is very difficult to evaluate the structural performance of traditional buildings one by one and estimate the vulnerability of whole area due to a large number of buildings and growing number of districts. We have proposed an onsite survey method of traditional districts [3], which includes the inquiring survey, structural properties survey, and district survey as shown in Table 4.1. Since the inquiring survey is a well-established tool for acquiring information in the district survey, it became an essential part of this survey method which can grasp the overall status of the building structure and risk perception of inhabitants rapidly. Therefore, in order to grasp the difference of risk perception of different regions, we analyzed the results of questionnaire survey which is part of inquiring survey in this paper.

4.2 Methods of questionnaire survey

4.2.1 General information of districts

To demonstrate the regional disparities, the questionnaire survey have been conducted in 7 traditional districts which are close to each other as a part of regional structural investigation of traditional districts, Owase (Nakai and Minato, Owase, Mie) [4], Ise (Ominato, Ise, Mie) [4], Kiragawa (Kiragawa, Muroto, Kochi) [5], Miyama (Kita, Miyama, Nantan, Kyoto) [6], Yuasa(Yuasa, Aridagun Yuasa, Wakayama) [7], Seki (Seki, Kameyama, Mie) [8], and Gojo, from the year 2005 to 2013 (Fig 4.1). General information of districts in terms of location, history, and a description of architecture and townscape of seven traditional districts are summarized in the first part of Table 4.2. Four of the investigated districts, Kiragawa, Miyama, Yuasa and Seki are designated important preservation districts of groups of traditional buildings (IPDGHB), and have been classified into commercial town, mountain village, brewer's quarter and post town [9]. Since Owase, Gojo and Ise are not IPDGHB, there are no information of designated time, area and type of these two districts [15]. In addition, Owase, Ise, Kiragawa and Yuasa are assumed tsunami stricken area when Nankai earthquake occurs [17].

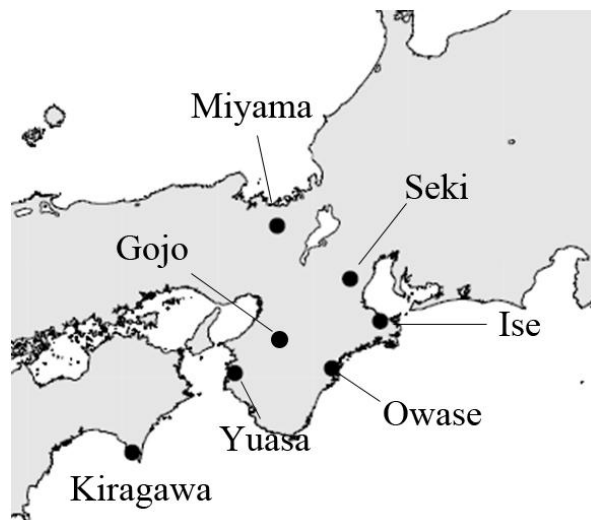


Figure 4.1 Location of 7 districts

4.2.2 Content of questionnaire survey

The questionnaire consist of 5 parts: a) Information of inhabitants, which includes the demographic information of the districts; b) General information of houses, which includes the information of structural type, age of houses, and application of seismic retrofits, etc.; c) Maintenance of houses, which refers the perception of inhabitants on house management and maintenance; d) Disaster experience of house, which includes the types of experienced of

disasters of the inhabitants and houses of different districts; e) Perception of Nankai and Tonankai earthquakes for four districts Seki, Kiragawa, Yuasa and Gojo for the disparities of risks perception of predicted affected areas of Nankai trough earthquake. The detailed items of questionnaire survey are shown in Appendix 1. The results will be presented and analyzed in this paper, except of the part of Maintenance of houses.

4.2.3 Distribution and collection of the questionnaire

Second part of Table 4.2, information of questionnaire survey describes the investigated time, number of respondents and cooperated sectors and individuals of the questionnaire survey. All the questionnaire sheets were distributed with the Municipal governments, NGO, or the local residential association as listed in Table 4.2.

4.3 Seismic risk

Compared among 7 investigated districts, the exceedance probability within 30 years is relatively lower in Miyama [16] (Fig 4.2). As shown in Figure 4.3 the value of ground motion of Miyama is small. Besides, the maximum values of the ground motion of Owase, Kiragawa, Ise and Yuasa are larger than the maxim value of engineering bedrock, therefore, seismic ground motions will be amplified in subsurface soil during earthquakes.

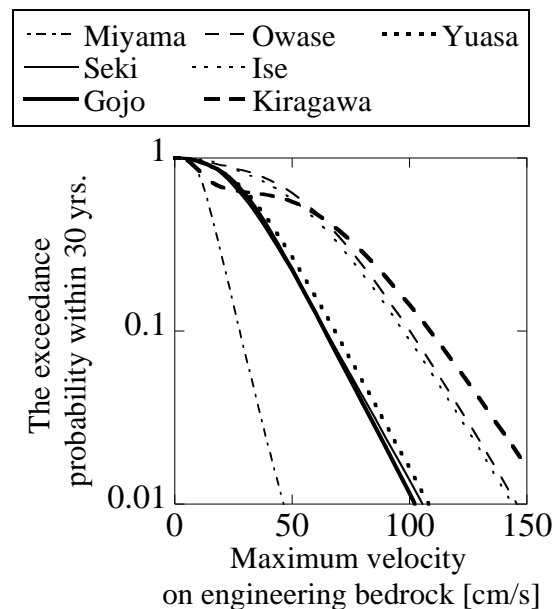


Figure 4.2 Seismic hazard curves of 7 districts

Table 4.2 General information and images of investigated districts

Districts	Owase ⁴⁾	Ise ⁵⁾	Kiragawa ⁶⁾	Miyama ⁷⁾	Yuasa ⁸⁾	Seki ⁹⁾	Gojo
Location	Nakai and Minato, Owase, Mie	Ominato, Ise, Mie	Kiragawa, Muroto, Kochi	Kita, Miyama, Nantan, Kyoto	Yuasa, Aridagun, Yuasa, Wakayama	Seki, Kameyama, Mie	Gojo, Nara
Time of investigation	2005	2005	2008	2010	2011	2012	2013
Number of respondents	78	43	28	14	176	132	76
Cooperated sectors and individuals	City planning sector of construction division of Owase city Chairmen of residential associations	Representative of local disaster prevention club Chairmen of residential associations of different districts.	Chairman of residential associations	Chairman of residential associations	Municipal government Chairmen of residential associations of different districts	Cultural properties sector Chairmen of residential associations of different districts	Education committee of Gojo City
Designated time and area	-	-	Oct.31.1997, 18.3 ha	Dec.8.1993, 127.5 ha	Dec.19.2006, 6.3 ha	Dec.10.1984, 25.0 ha	-
Type	-	-	Village	Village	Industrial town	Post town	-



Owase



Ise



Kiragawa



Miyama



Yuasa



Seki



Gojo

Figure 4.4 describes the relationship of the maximum ground motion with the height of tsunami wave in 4 assumed tsunami- stricken districts. The ground motion will be more severe in the places near Nankai trough, and the amount of tsunami is high [17].

According to the above analysis, the probability of strong ground motions is very high in Owase, Ise, Kiragawa, moderate in Yuasa, Seki, and and Gojo, low in Miyama. Tsunami risk is high in Kiragawa, Owase, Ise and Yuasa owing to their geographical locations.

The investigation results of seven districts are presented the order of Miyama, Gojo, Seki Yuasa, Owase, Ise and Kiragawa according their different levels of seismic risk.

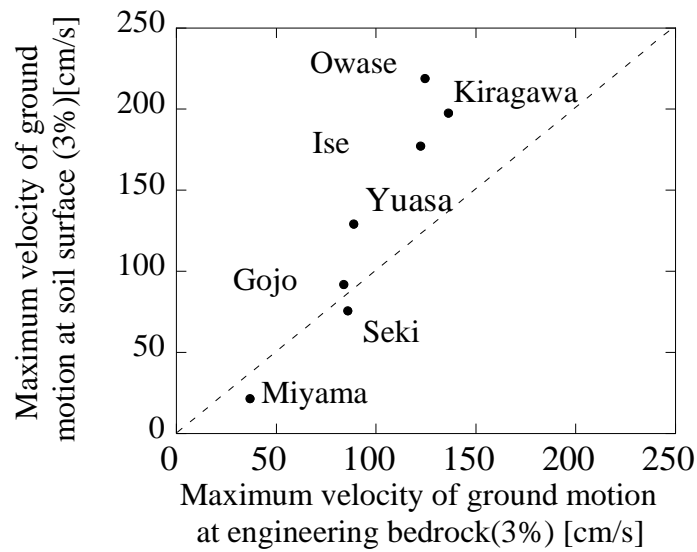


Figure 4.3 Relationship between maximum velocity of ground motion and engineering bedrock

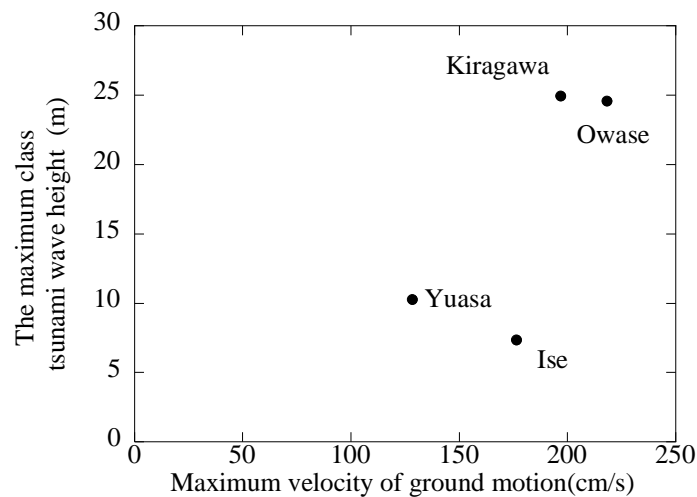


Figure 4.4 Relationship between maximum velocity of ground motion and tsunami wave height

4.4 Results of Questionnaire survey

4.4.1 Demographic information

There is a general consensus that demographic status, about age of the inhabitants and family structure, etc., is one of major factors of estimating regional social vulnerability [18]. For example, aged population is always regarded as lacking of resilience due to the mobility constraints.

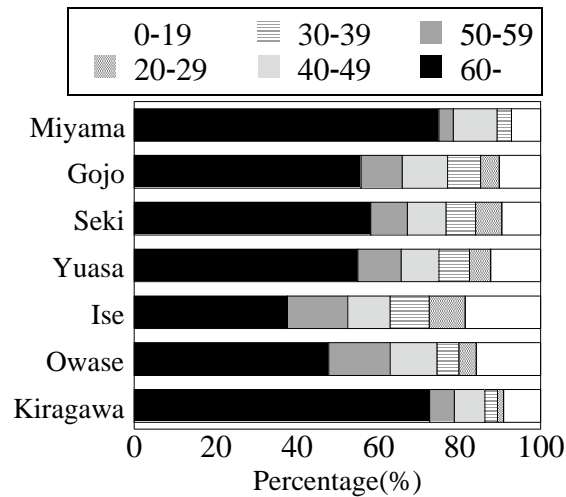


Figure 4.5 Age distribution by regions (Q.1)

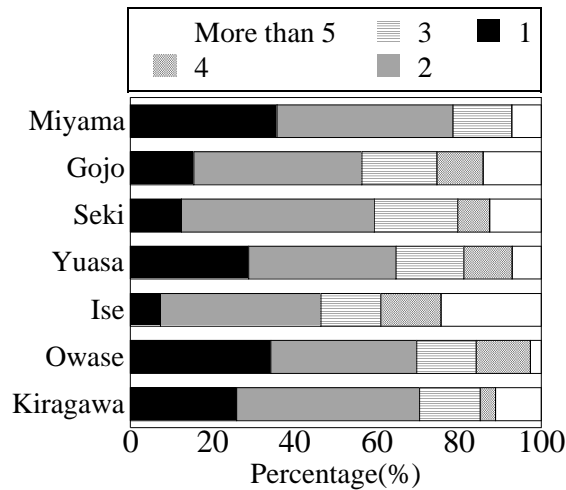


Figure 4.6 Percentage of number of household member (Q.1)

Results of Q.1 from Appendix 1 are represented in Fig 4.5, Fig 4.6 and Fig 4.7. Trend of aging population can be clearly observed from Fig 4.5, more than half of the inhabitants in surveyed districts are over 60 years old except in Ise, and less than 30% of inhabitants are under 30 years old. Figure 4.6 illustrates Percentage of the number of household members by regions. The proportion of one or two- person household is larger in Miyama, Owase, Kiragawa and Yuasa, while it is relatively smaller in Ise. As indicated in Fig 4.7, there are many aged people (over 60 years old) live by themselves. The proportion of aged population of 1-person households reached 100% in Miyama, Seki and Kiragawa, and varies from 67% to more than 86% in other 4 districts.

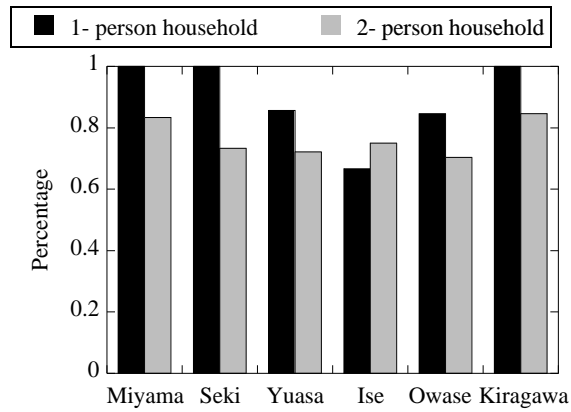


Figure 4.7 Percentage of aged people (over 60 yr.) of 1 or 2 person households (Q.1)

4.4.2 Information of the houses

Figure 4.8 shows the distribution of house ages (Q.8). Houses in Miyama are rather old, and more than 70% of the houses are over 100 years old, and almost half of the houses over 150 years old, with the rest over 50 years old. In Seki nearly 40% of the houses are over 100 years old. Around 15% of houses are over 100 years old in Owase, Ise, Kiragawa and Yuasa. Figure 4.9 illustrates the proportion of traditional framing constructed houses (including the traditional houses reformed by the non- traditional methods) (Q.7). The majority of the houses are traditional framing constructed, and this percentage reached 100% in Miyama.

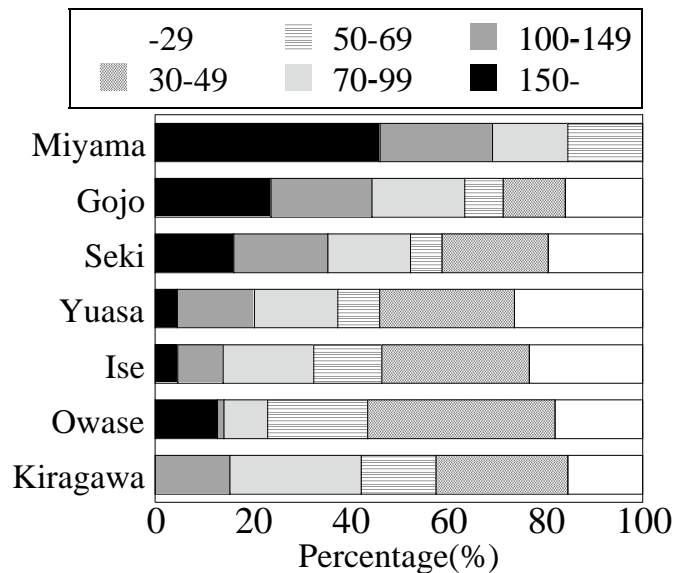


Figure 4.8 Age of houses (Q.8)

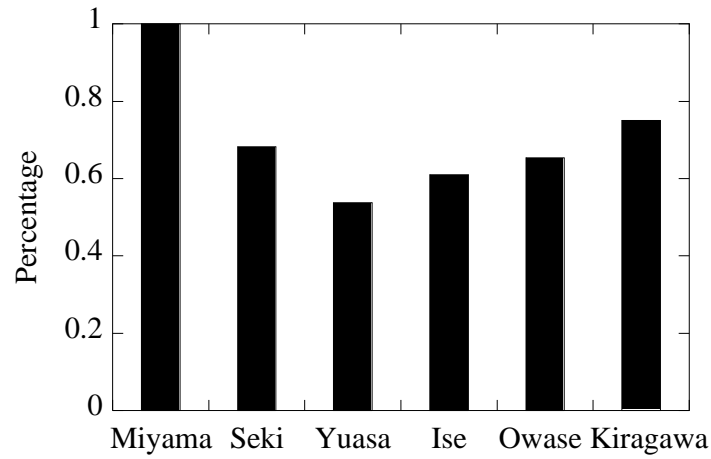


Figure 4.9 Percentage of traditional framing constructed houses (Q.7)

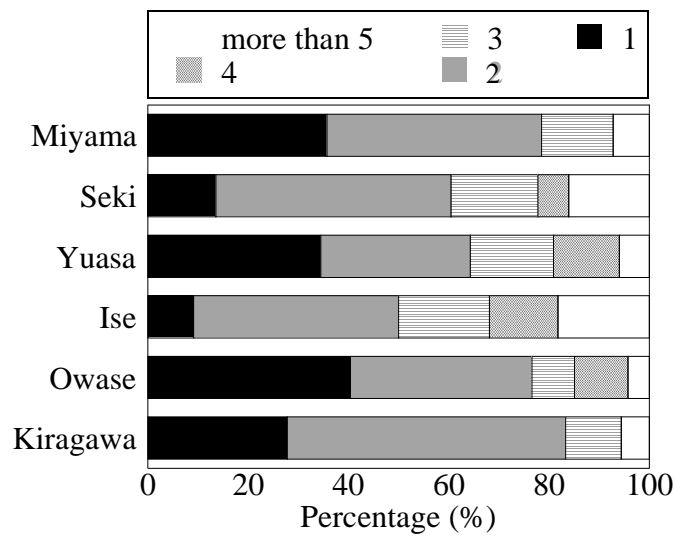


Figure 4.10 Percentage of number of household member of traditional houses (Q.1,Q.7)

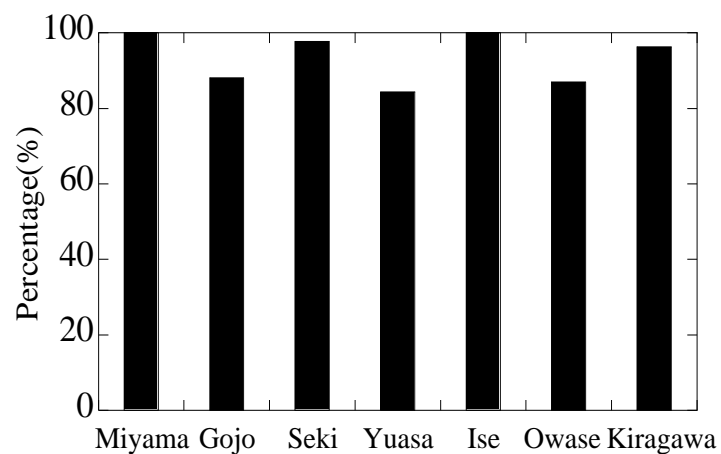


Figure 4.11 Percentage of owned houses (Q.5)

Percentage of number of household member of traditional houses is around 80% in Miyama, Owase and Kiragawa. Half of the households live in traditional houses in Ise have 3 or more

family members (Fig 4.10, Q.1,Q.7). Figure 4.11 shows the percentage of rented houses (Q.5). All the respondents own their houses by themselves in Miyama and Ise, and the rate of rented houses in other 5 districts is also very low, around 15% in Owase and Yuasa, and around 3% in Seki and Kiragawa.

4.4.3 Disaster preparedness

It is evident from Figure 4.12 that there is a considerable proportion of respondents concern about earthquakes in surveyed districts except for Miyama where the seismic risk is very low (Q.24). Respondents from Owase have special concerns about Tsunami, and the percentage of which reaches 86%. No one worries about Tsunami in Miyama and Seki owing to the relatively better geographical locations. Figure 4.13 shows the types and percentages of the experienced disasters of the respondents (Q.23). The majority of the respondents from all the districts have experienced typhoon. No one experienced earthquake in Miyama and no one experienced tsunami in Kiragawa, Miyama and Gojo. 69 % of the respondents from Kiragawa experienced earthquakes.

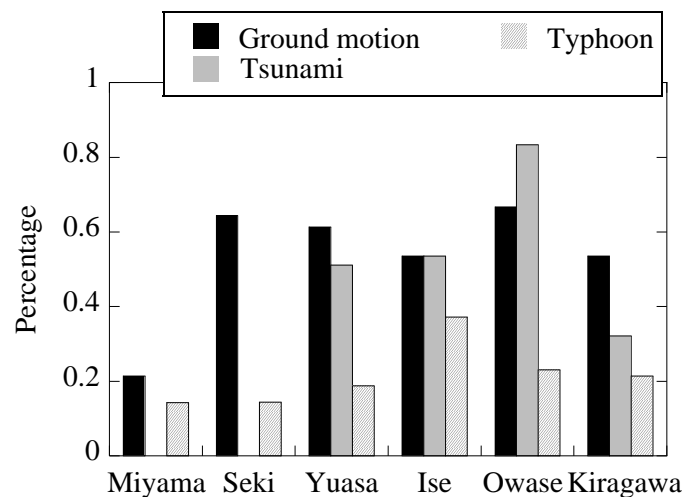


Figure 4.12 Feared disasters (Multiple selections) (Q.24)

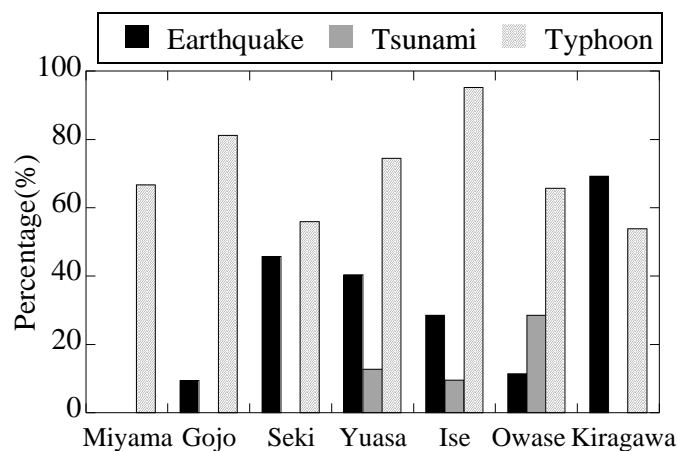


Figure 4.13 Experienced disasters (Multiple selections) (Q.23)

Figure 4.14 reveals that the majority of respondents who are concerned about earthquakes

are taking countermeasures against the disasters, and the percentage varies from 67% in Miyama, to 93% in Kiragawa(Q.24,Q.25). Figure 4.15 shows the content of the preparedness done by respondents (Q.25). With the countermeasures, respondents are more likely to engage and expend more effort to fix furniture and storage food and water than other measures, percentage of seismic retrofit is very low, and no one conducted seismic retrofit in Miyama and Owase.

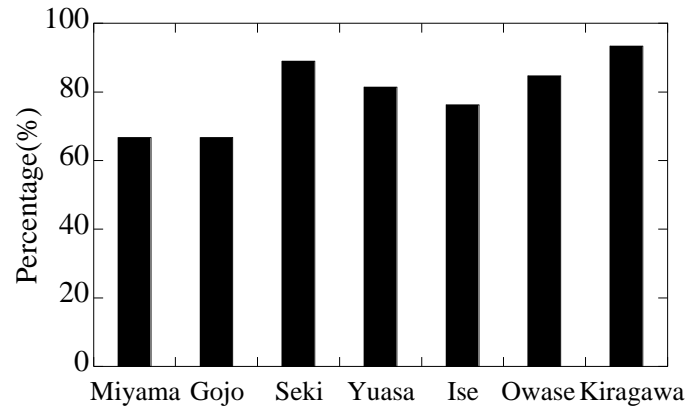


Figure 4.14 Percentage of preparedness among who concerns about earthquakes (Q.24,Q.25)

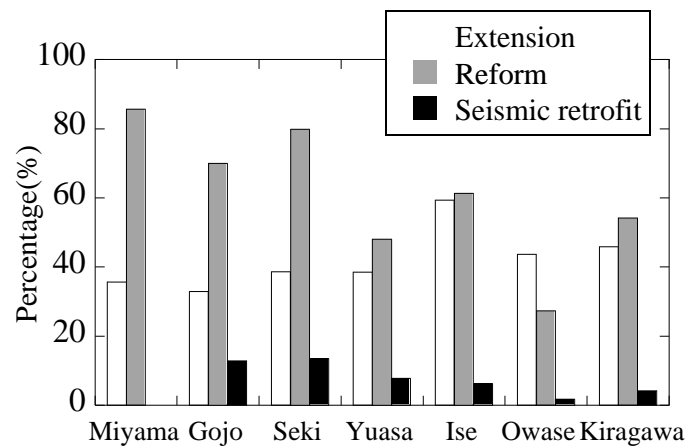


Figure 4.15 Earthquake preparedness (Multiple selection) (Q.25)

Figure 4.16 shows the percentage of houses being preserved in terms of extension, seismic retrofit, and reform. Since Q.17 and Q.18 discuss the issue of preservation treatments and plans in context of status of properties, the results of percentage of seismic retrofit are different from Q.25. The percentage of seismic retrofit is very low, less than 13% and no one conducted seismic retrofit in Miyama. More than half of the houses in the investigated districts except Owase had been reformed (Q.17). It is advisable to conduct seismic retrofit during the application of reform or extension in the districts with high or moderate seismic risk. The seismic risk is low in Miyama, to mitigate the deterioration of structure, yet the maintenance of houses should not be ignored 6).

Figure 4.17 shows the percentage of inhabitants who plan to preserve their houses (Q.18). The majority of the respondents have no plans of preservation. The percentage is relatively higher in Miyama and Kiragawa, 23% and 25% respectively. And less than 10% of the respondents have preservation plans in Seki, Owase and Ise. As shown in Fig 4.18, among the respondents with preservation plans, reform and seismic retrofit are most popular. There are also quite a number of respondents considering the overall repair for their houses (Q.18).

Though the designation of IPDGHB brings some constraints for application of seismic retrofit, however, it does not influence the decision making of the inhabitants to do so, and there are no distinct disparities between the designated districts and un-designated districts for the reasons of reluctance of application of seismic retrofit. Q.26 discussed the reasons for not conducting the seismic retrofit, and among the designated districts, the percentage of respondents who regard the designation as obstacles of conducting preservation, 0% in Miyama and Yuasa, 5.2% in Seki, 9.5% in Kiragawa. There are mainly two reasons for inhabitants to be reluctant to conduct retrofits for their houses, for one thing is the expense of retrofits is too high, for another, they do not think their offspring will continue to live in the houses in the future. More than 20% of the respondents from Miyama and Kiragawa believe there are no problems with their houses (Fig 4.19, Q.26).

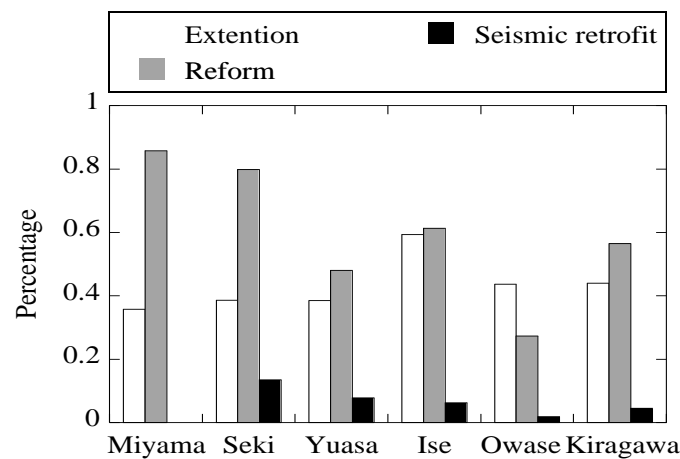


Figure 4.16 Percentage of preserved houses (Multiple selections) (Q.17)

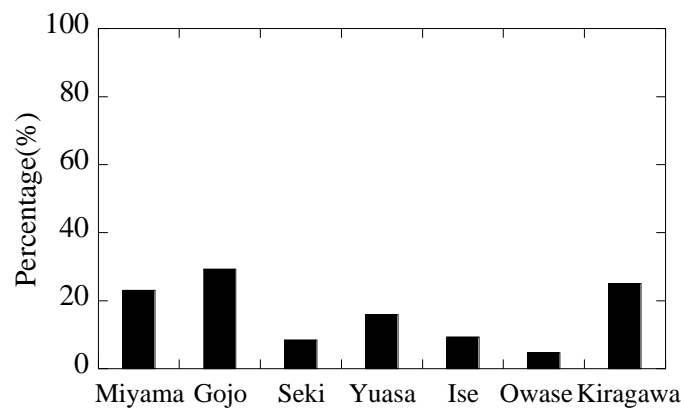


Figure 4.17 Houses with seismic retrofit plan (Q.18)

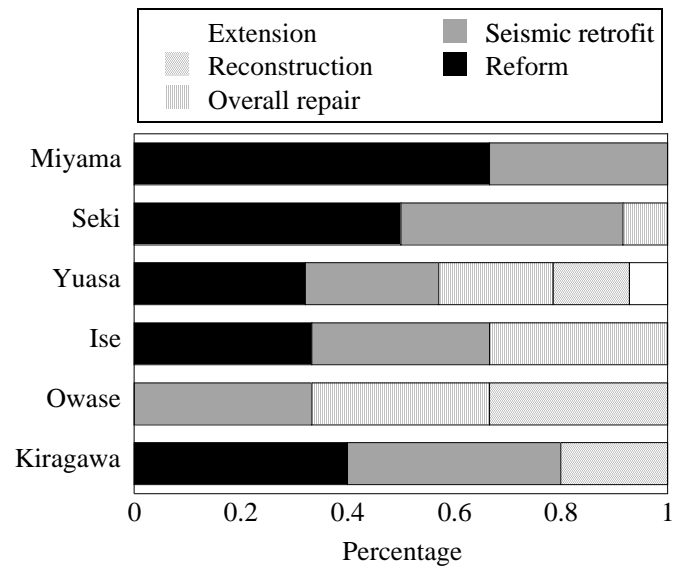


Figure 4.18 Preservation plan (Q.18)

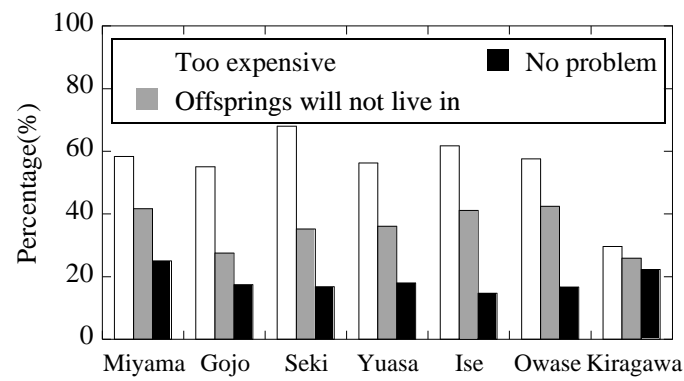


Figure 4.19 Obstacles of conducting seismic retrofit (Q.26)

4.4.4 Seismic risk perception

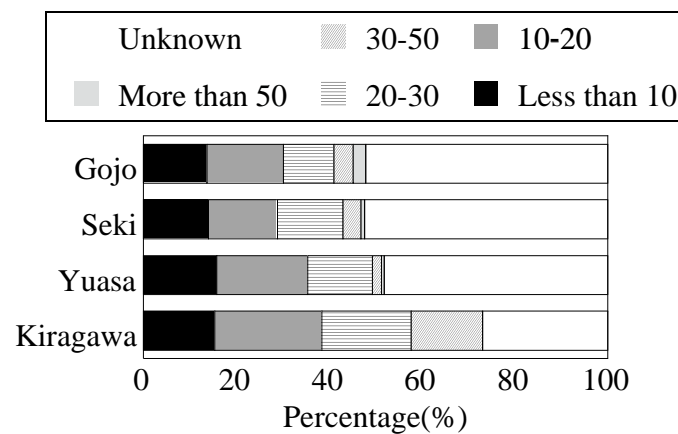


Figure 4.20 Estimated time of Nankai and Tonankai earthquakes (Q.27)

Based on the announced data of seismic data announced by The Headquarters for

Earthquake Research Promotion, the probability occurrence of Nankai trough earthquake is 20% within 10 years, 60~70% within 30 years, and 90% within 50 years [18].

Among the 3 districts, respondents from Kiragawa show more concern about the coming of Nankai and Tonankai earthquakes. As shown in Fig 4.20, around half of the respondents from Seki and Yuasa, together with more than 70% respondents from kiragawa believe Nankai and Tonankai earthquakes will come within 50 years or less (Q.27).

Figure 4.21 shows the estimated consequences from Nankai and Tonankai Earthquakes of the respondents (Q.29). Almost 40% of the respondents in Seki and Yuasa have no idea about the consequences of earthquakes. By contrast in Kiragawa, almost 80% of the respondents believe that their houses will be damaged to some extent during the earthquakes. Although Seki and Yuasa were investigated after the 2011 off the Pacific Coast of Tohoku Earthquake, which is different from the situation of the questionnaire survey in Kiragawa, no significant difference of risk perception before and after earthquake can be observed from the surveyed data.

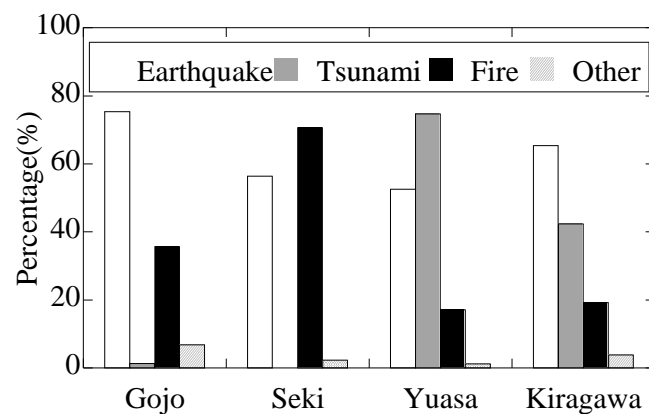


Figure 4.21 Worried disasters (Multiple selections) (Q.21)

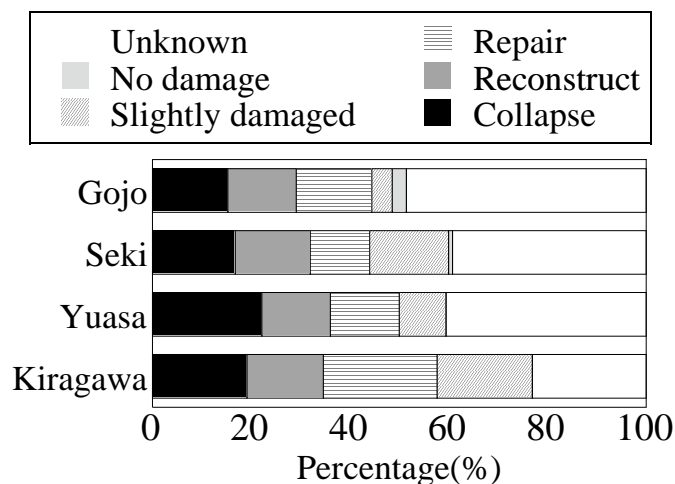


Figure 4.22 Estimated consequences from Nankai and Tonankai Earthquake (Q.29)

4.4.5 Consciousness of inhabitants to maintenance management

Carrying out maintenance management for the house appropriately is important for anti-earthquake procedures. In this chapter, the repair of disaster damaged part of houses,

situation of termite damage, frequency and content of maintenance are reported, and the inhabitants' consciousness of the maintenance management is analyzed.

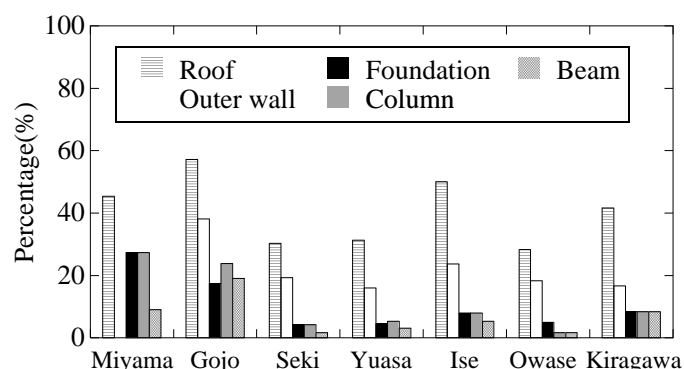


Figure 4.23 Positions of the disaster damage (Multiple selection)(Q.20)

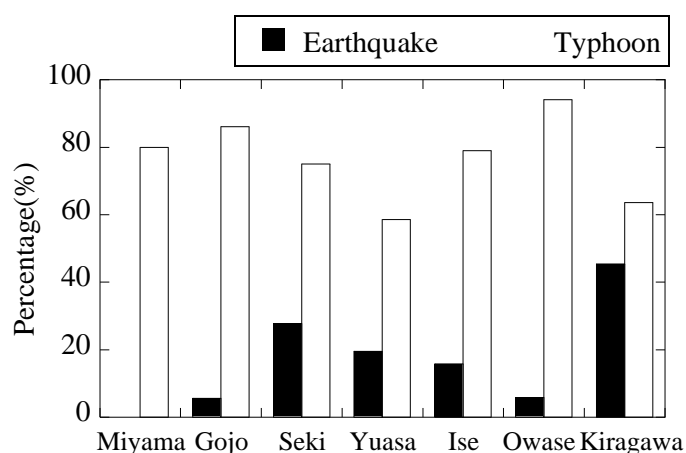
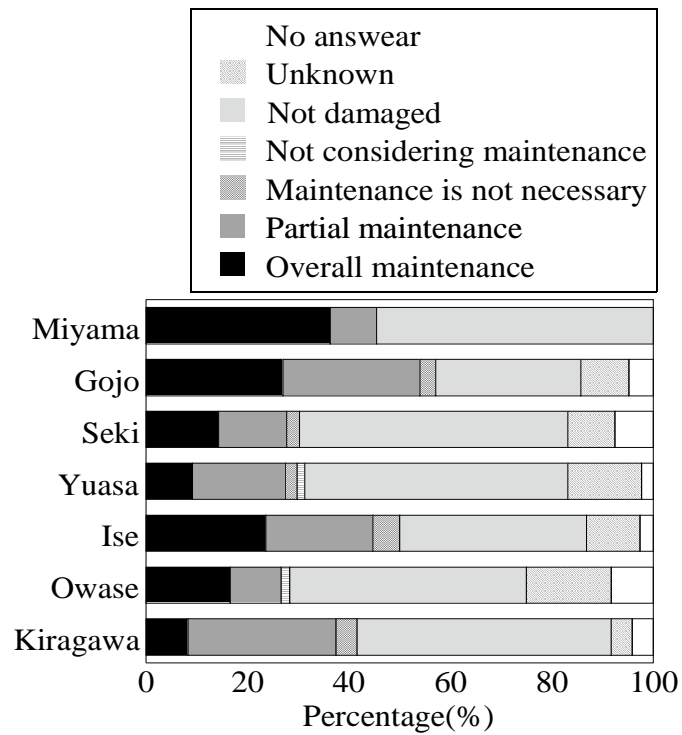
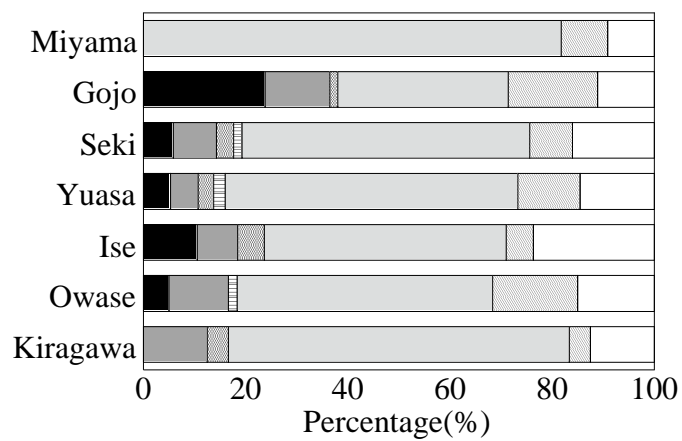


Figure 4.24 Causes of roof damage (Multiple selections) (Q.23)

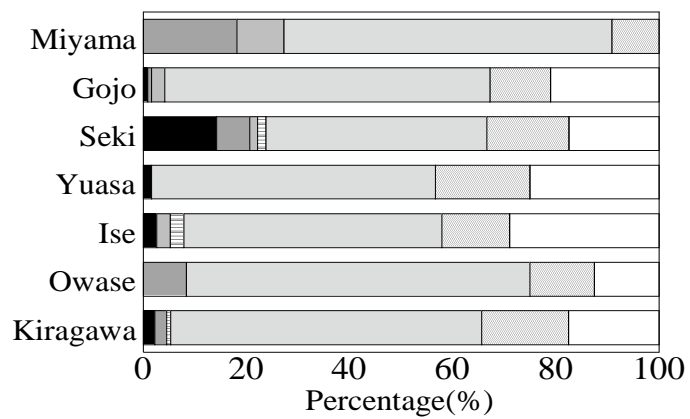
The positions of the disaster damage of the houses are shown in Fig 4.23. As for all the districts, the roof is the most frequently damaged position of the house. Because Gojo was seriously affected by Isewan Typhoon and inundation damage occurred in the Yoshinogawa basin, besides the roof, other parts of the houses in Gojo have also been seriously damaged. In addition, though there was no earthquake in Miyama, compared with other districts, there are more damaged columns and foundations of the houses, because the age of the houses is very old, and often affected by the heavy snow, inundation and sediment disasters. As shown in Fig 4.24, most damage to roofs has been done by typhoons. The damage ratio is very high in Seki and Kiragawa due to the earthquakes. In particular, the tiles fell down in Kiragawa during the Showa Nankai earthquakes.



(a) Roof

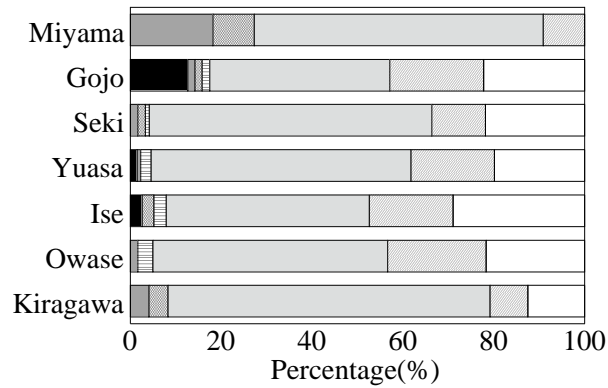


(b) Outer wall



(c) Column

Figure 4.25 Applied treatments (Q.22) (continued)



(d) Foundation

Figure 4.25 Applied treatments (Q.22)

Figure 4.25 shows the damage status of the roof, outer wall, column, and foundation and the treatments of the damaged houses are expressed in terms of overall repair, partial repair, did not conduct maintenance but regarded maintenance as necessary, not considering maintenance, unknown, and no answer. Among all the damaged houses, the ratio of overall repair and partial repair is very high, especially in Miyama, all the damaged houses have been repaired. Besides, the houses in Gojo, the ratio of repair is very high for every part of the houses in Gojo. However, for all the districts, there are many respondents who replied “unknown”, so it is not so accurate to estimate the damage status for all the houses.

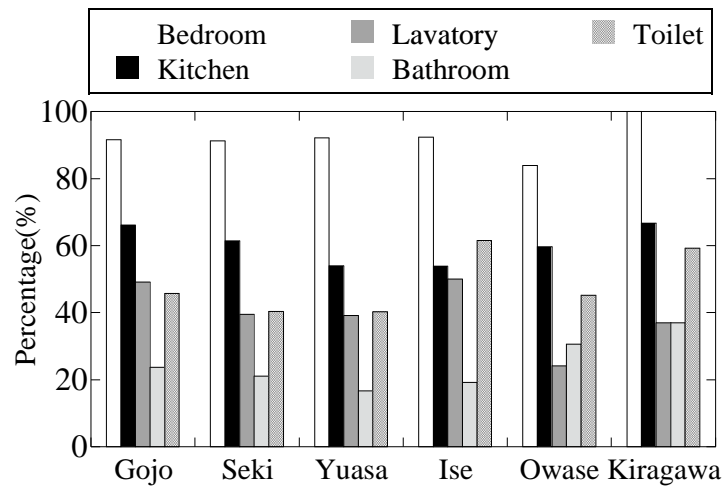


Figure 4.26 Columns & beams could be observed locations (Multiple selections) (Q.15)

Whether the columns and beams could be observed or not is important for inhabitants to grasp the status of termite damage and decay. As shown in Fig 4.26, except Miyama, where the question was not included in the questionnaire, for all the districts, more than 80% of the houses, beams and columns could be observed in bedroom, however, in the kitchen and lavatory, where the risk of decay and termite damage is high, the columns and beams were almost not observed, thus, it is difficult for inhabitants to grasp the status of decay and termite

damage for their houses.

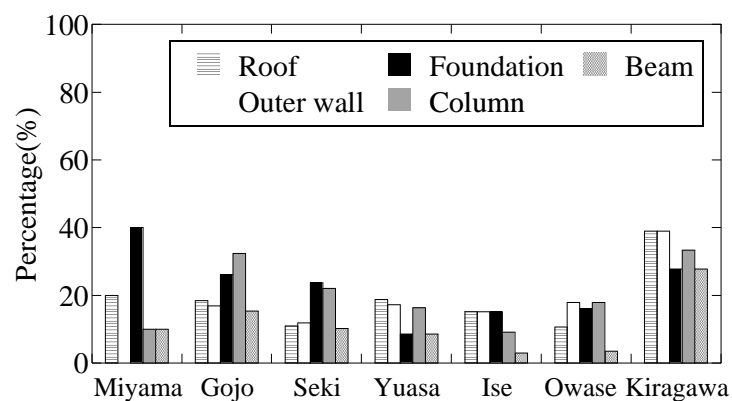


Figure 4.27 Occurrence and treatment of decay and termite damage (Q.21)

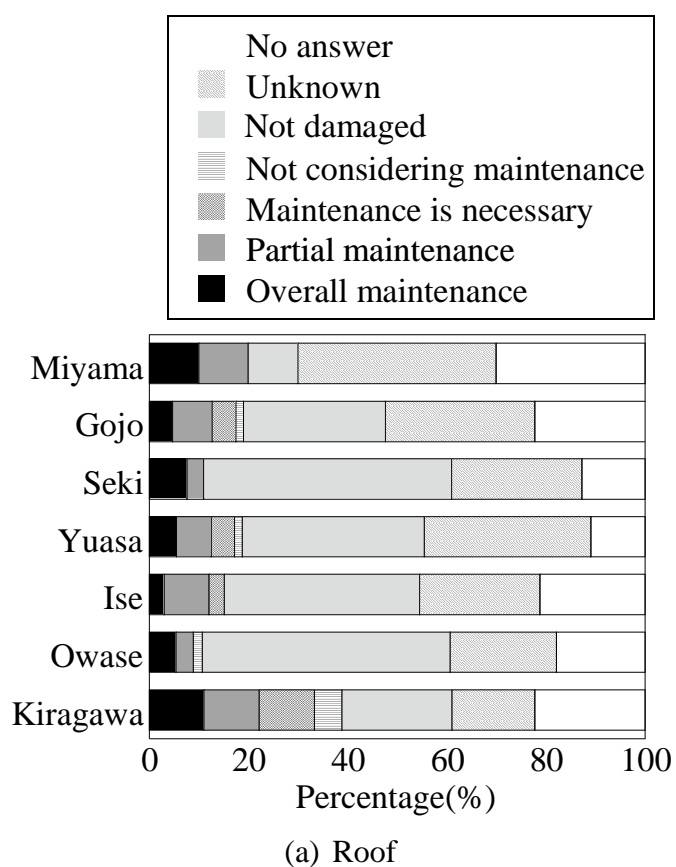
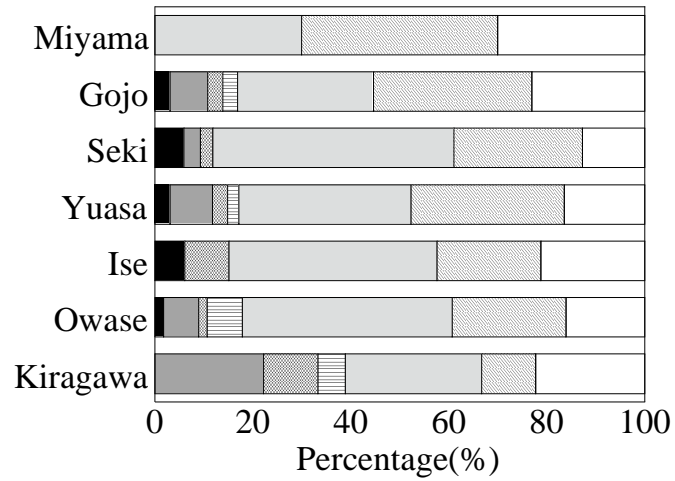
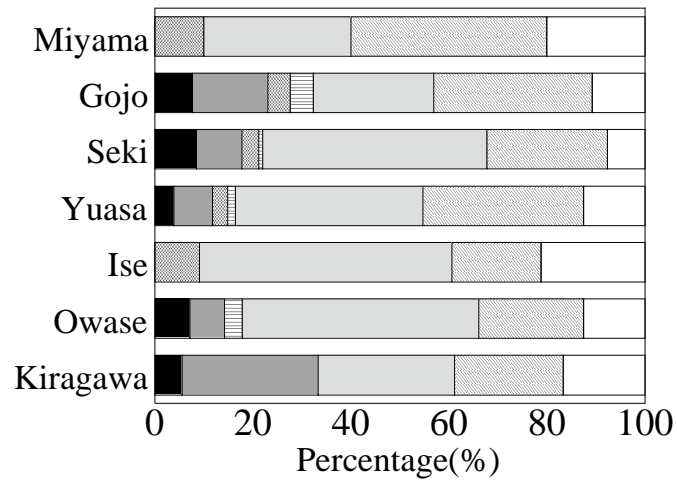


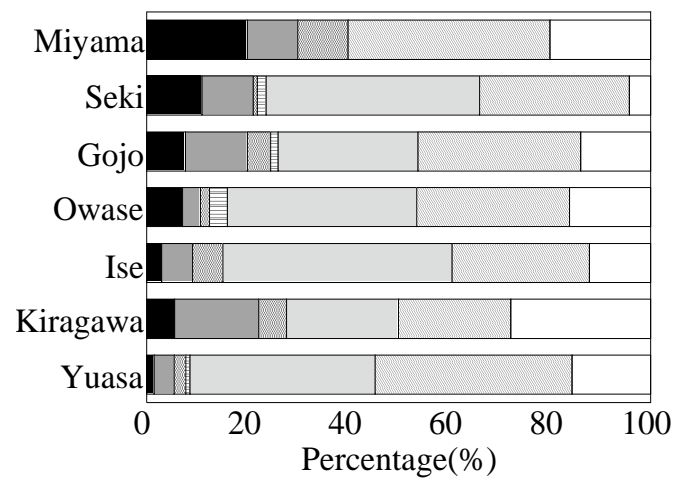
Figure 4.28 Decay and termite damage status (Q.21) (continued)



(b) Outer wall



(c) Column



(d) Foundation

Figure 4.28 Decay and termite damage status (Q.21)

Figure 4.27 shows the positions of the decay and the termite damage to the houses in different districts. More than 20% of the houses in Kiragawa were damaged, and the damage ratio is higher than other districts. The damage ratio of the foundation is very high, around 40% in Miyama. The decay and termite damage status of the roof, outer wall, columns and foundation is shown in Fig 4.28. The repair ratio is high for the columns and foundation, and low for the roof and outer wall in Kiragawa, and for the rest of the districts, the ratio of partial repair is high, and many people replied “unknown” in the districts including Miyama and Kiragawa.

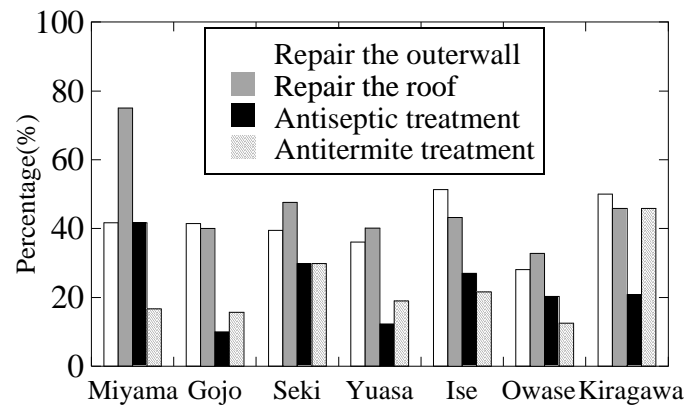


Figure 4.29 Content of maintenance (Multiple selections) (Q.20)

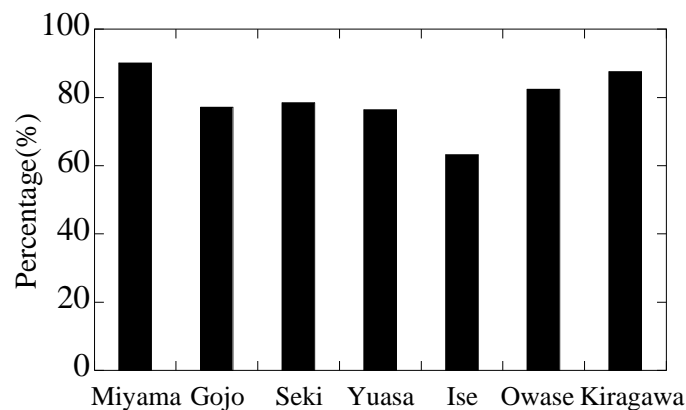


Figure 4.30 Long- term cooperated carpenters (Q.21)

Figure 4.29 shows the contents maintenance. As shown in Figure 4.30, 90% of the houses in Miyama, and more than 60% of the houses for the rest of the districts have long- termed cooperated carpenters, therefore, it is easy for the inhabitants to conduct the maintenance for their houses.

4.5 Discussion

4.5.1 Hazards and disaster perception

Table 4.2 C_y , PGV, tsunami height of survey districts

Districts	C_y			PGV (3%) [cm/s]	Height of tsunami wave [m]
	C_{yR}	C_{yS}	Weak axis		
Kiragawa	0.25	0.49	0.25	197.2	24.9
Ise	0.26	0.56	0.26	176.8	7.3
Owase	0.34	0.55	0.34	218.5	24.5
Yuasa	0.30	0.50	0.29	128.7	10.2
Miyama	0.36	0.32	0.29	21.1	

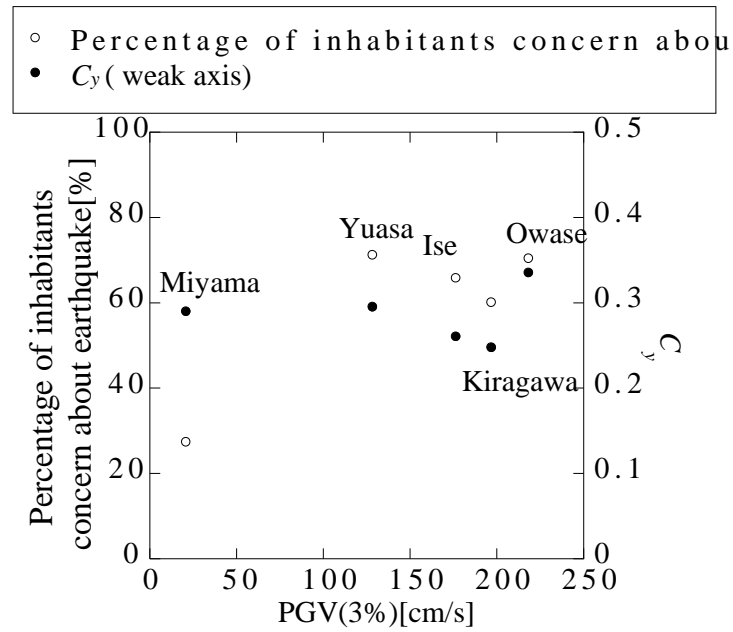


Figure 4.31 Relation of PGV and disaster perception

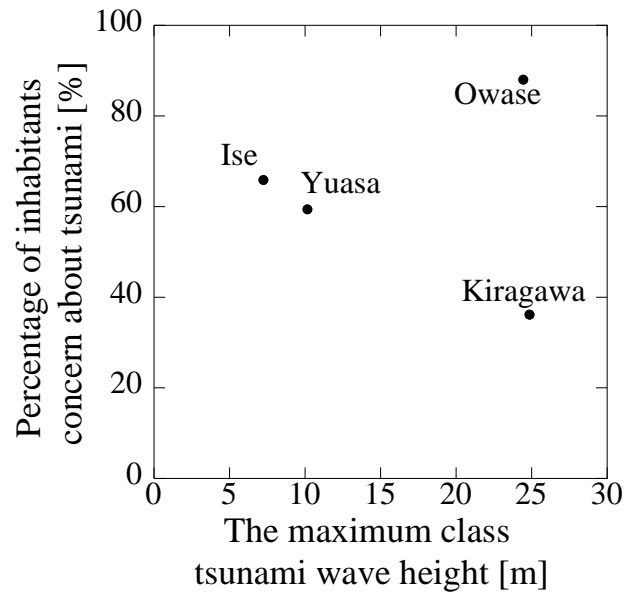


Figure 4.32 Relation of tsunami wave height and disaster perception

The results of questionnaire survey on disaster perception are discussed with the results of average value of the yield base coefficient C_y and level of disaster risks of the surveyed districts in this section. Table 4.2 shows the average value of C_y of the ridge direction, span direction and weak axis of the houses in 5 surveyed districts, the value of PGV (3%)[cm/s], and the maximum height of tsunami wave. Figure 4.33 describes the relation of disaster perception and the values of PGV, and average value of C_y of weak axis also is also indicated. Except for Miyama, in which the seismic probability is very low, there is no distinct difference for the ratio of inhabitants concern with earthquakes for the rest of districts, though the seismic probability varies. Figure 4.34 shows the relation of disaster perception with the tsunami wave height, though the predicted height of tsunami wave is very large in Kiragawa, the ratio of inhabitants with tsunami concerns is low, and this may related with their previous experience of tsunami without serious damages on their houses.

Table 4.3 Moisture content of column, deterioration status and treatments

Districts	Height of floor (mm)	Moisture content of column (%)				Results of questionnaire		
		Average value		Standard deviation		Percentage of treatment		Percentage of households with termite damage
		Under floor	1st floor	Under floor	1st floor	Antiseptic	Anti-termite	
Kiragawa	512.7	34.23	17.05	15.75	3.84	20.8	45.8	77.8
Ise	535.0	49.10	-	22.79	-	27.0	21.6	39.4
Owase	-	-	-	-	-	20.3	12.5	39.3
Yuasa	426.9	28.60	15.28	9.76	2.95	12.2	19.0	35.9
Seki	-	25.77	16.51	6.52	5.02	29.8	29.8	35.6
Miyama	367.8	39.88	21.52	15.10	2.33	41.7	16.7	60.0
Gojo	-	41.92	17.73	16.42	2.87	10.0	15.7	49.2

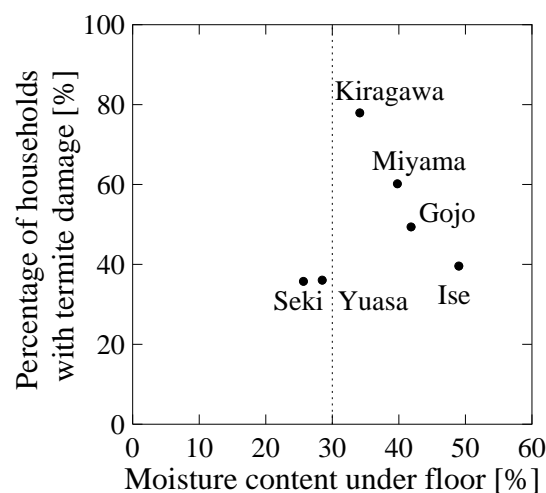
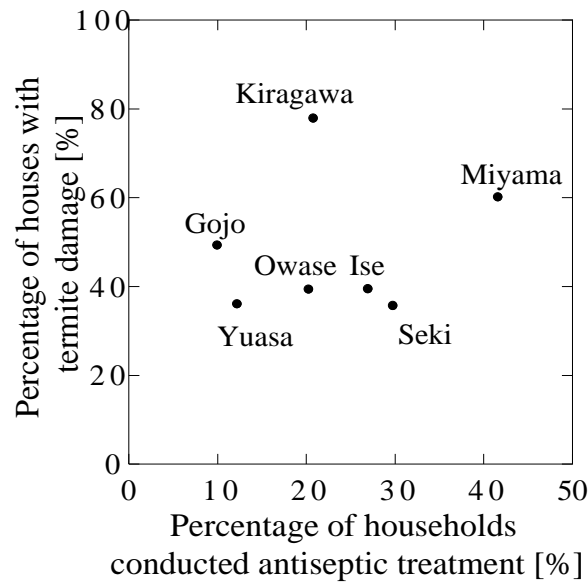
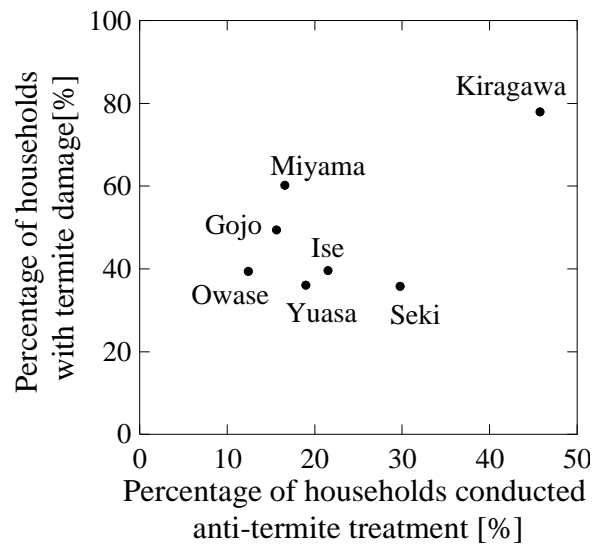


Figure 4.33 Relation of moisture content and percentage of houses with termite damage



(a) Antiseptic treatment



(b) Anti- termite treatment

Figure 4.34 Relation of deterioration status and treatment

To analyze the deterioration status and the maintenance behavior, the average value of moisture content of column from structural investigation (except for Owase), deterioration status and treatments (results from questionnaire survey) of the houses in the surveyed districts are described in Table 4.3. Figure 4.33 shows the relation of moisture content and percentage of houses with termite damage, the moisture content is high for the districts as Kiragawa, Gojo, Miyama, and Ise, and ratio of termite damage is very high in Kiragawa. Figure 4.34 shows the relation of deterioration status and treatment, and we can see the decay and termite damage is quite serious for the houses in Kiragawa, that inhabitants are fully aware with the situation, and make efforts to mitigate the damage.

4.5.2 Proposal on interventions by districts

Based on the analysis of results of questionnaire survey and disaster risks, results of structural investigation, noticeable facts are highlighted and some interventions to mitigate the disaster damage are proposed for each district as following:

- Miyama: Though probability of seismic activity is low and no tsunami in Miyama, there is a large proportion of aged population and old houses, and moisture content of column is very high. Daily maintenance, in term of ventilation, anti- termite is highly recommended for the houses. Long- term monitoring for the houses is also essential.
- Gojo: The probability of seismic activity is moderate in Gojo, and there is no threat of tsunami. Besides the maintenance and monitoring, in case of the occurrence of the earthquake, the seismic retrofit needs to be applied to the houses with poor seismic performance. The typhoon frequently attacks this area, and roof of house is easy to be damaged. The traditional technique of construction of the roof needs to be improved.
- Seki: The probability of seismic activity is moderate in Seki, and there is no threat of tsunami, and the inhabitants have no plan to conduct seismic retrofit. Besides the maintenance and monitoring, in case of the occurrence of the earthquake, the seismic retrofit needs to be applied to the houses with poor seismic performance. The traditional houses in Seki used to be seriously damaged by fire; therefore, more attention needs to be paid on reducing ignition.
- Yuasa: The probability of seismic activity is moderate in Yuasa, and there is a threat of tsunami. The proportion of 1or 2 person house hold is large. Besides the maintenance, monitoring and seismic retrofit for the houses, the inhabitants needs to make more preparedness for disasters, like participation of disaster prevention drills, and creating emergency team to response the disaster.
- Ise: The probability of earthquake and tsunami is high in Ise, and the moisture content of column is high in Ise, while the rate of application of termite damage is low. Interventions should be taken in both hard ways and soft ways, the maintenance and seismic retrofit is highly recommended and preparedness for disasters is also essential, like participation of disaster prevention drills, making evacuation plan, and creating emergency team to response the disaster.
- Owase: The probability of earthquake and tsunami is high in Owase. Though the rate of disaster concern is high in Owase, the rate of application of seismic retrofit is very low. The maintenance, monitoring and seismic retrofit is highly recommended and preparedness for disasters is also essential, like participation of disaster prevention drills, making evacuation plan, and creating emergency team to response the disaster.
- Kiragawa: The probability of earthquake and tsunami is very high in Kiragawa, however the rate of disaster concern is very low. Besides the interventions mentioned above, the promotion of disaster awareness is very important to avoid lost caused by the attitudinal problems.

4.6 Conclusion

Since questionnaire survey is a fundamental approach to assess regional disaster vulnerability, we proposed a questionnaire survey method based on conventional questionnaire survey methods and regional built environment inspection which can efficiently be applied to district survey both for cultural heritage conservation and regional security management. Major conclusions are drawn as follows:

- (1) Based on the analysis of the results from questionnaire survey, all the surveyed traditional districts share many similarities: A large number of old traditional houses exist; the problem of aging population is quite obvious in all the surveyed districts and there is a large number of one or two-person households consisting of aged people, especially for Miyama and Kiragawa; though the ratio of the ownership of the houses is very high, people still are reluctant to conduct retrofit for their houses, mainly because of the economic pressures and problem of property inheritance; though the designation of IPDGHB brings some constraints for application of seismic retrofit, however, it does not influence the decision making of the inhabitants to do so, and there is no distinct disparities between the designated districts and un-designated districts for the reasons of reluctance of application of seismic retrofit.
- (2) The disaster countermeasures should be different according to the local disaster risks. Comparing with Kyoto, the yield base shear coefficient (C_y) of the traditional houses in surveyed districts is not low. The values of estimated PGV & tsunami height vary distinctively among the surveyed districts, and interventions for mitigation of disaster damage are proposed for each district.
- (3) Besides the seismic performance of the house, the risk perception of the inhabitants also affects the district vulnerability. As for Miyama, the ratio of inhabitants who concern earthquake is very low, because of the low seismic probability. However, the house in Miyama is very old and to prepare against the unexpected earthquake, effort on maintenance of houses is important to mitigate the deterioration of seismic performance. The ratio of inhabitants with tsunami concerns is also low in Kiragawa, because in the last Nankai earthquake the damage from tsunami was not severe. However, the value of the predicted height of tsunami wave of the coming Nankai earthquake is very large for Kiragawa, the promotion of risk awareness and disaster preparedness is highly recommended.

Appendix 1 Questionnaire

■ Information of residents

Q.1 Family members

Gender/Age	0-19	20-29	30-39	40-49	50-59	60-
Male						
Female						

Q.2 Respondent

☐ Female ☐ Male Age ()

■ General information of houses

Q.3 Whether the house is located in IPDGH

☐ Yes ☐ No

Q.4 Type of house

☐ Kodate ☐ Nagaya ☐ Apartment ☐ Other __

Q.5 Ownership of the house

☐ One's own house ☐ Rented house

Q.6 Usage of the house

☐ Residential house ☐ Commercial and Residential complex

☐ Shop ☐ Other__

Q.7 Construction method of the house

☐ None- wooden prefabricated structure(eg. light steel frame)

☐ Traditional framing construction method (timber structure with columns, beams and crosspieces)

☐ Conventional framing construction method(mixed using metal components)

☐ Wood prefabricated construction method

☐ Two-by-four construction method (construction method using the material of the cross- section approximately of 2 × 4 inch)

☐ Cannot understand

☐ Other__

Q.8 Age of house () yr.

Q.9 Length of your staying

☐ - 10yr. ☐ 10-20 yr. ☐ 20-30 yr. ☐ 30-50 yr. ☐ 50- yr.

Q.10 Number of stories

☐ 1 story ☐ partially 2 stories ☐ 2 stories ☐ 3 stories

☐ Other__

Q.11 Building area

☐ -15Tsubo ☐ 15-25Tsubo ☐ 25-35Tsubo ☐ 35-45Tsubo

☐ 45~55Tsubo ☐ >55Tsubo ☐ Unknown

Q.12 Type of roof

☐ Tiled roof ☐ Thatched roof ☐ Slate roof ☐ Unknown

☐ Other__

Q.13 Material of outer wall

☐ Planking ☐ Plaster ☐ Mud wall ☐ Brick ☐ Siding

☐ Unknown ☐ Other__

Q.14 Whether ventilation openings exist in following locations?

☐ Under floor ☐ Roof ☐ Kitchen ☐ Lavatory ☐ Bathroom

☐ Toilet

Q.15 Whether columns or beams can be seen in following locations?

☐ Living room ☐ Shop ☐ Kitchen ☐ Lavatory ☐ Bathroom ☐ Toilet

Q.16 Whether following problems occurred in your house?

☐ House was swayed by strong wind ☐ Floor is inclined ☐ Sound from floor ☐ Wind leak ☐ Musty smell ☐ Water leakage, ☐ Condensation of moisture ☐ Hard to open and close windows and doors ☐ Poor drainage of site ☐ Poor natural lighting of site ☐ Gaps exist between columns and joineries

Q.17 Experience of extension, renovation, seismic retrofit of the house

Time (before)/ Location	-10 yr.,	10-30 yr.,	30-50 yr.,	50-100 yr.,	100- yr.,	None
Kitchen						
Lavatory						
Bathroom						
Toilet						
Bedroom						
Shop						
Other__						
Other__						

■ Maintenance of house

Q.20 Frequency of following maintenance

	Daily/ Weekly	Every 1-2 yr.	Every 5 yr.	Every 10- yr.	None
Dried tatami					
Ventilation of the bathroom					
Repair of the outer wall					
Repair of roof					
Cleaning of rain gutters					
Cleaning of					

Weeding and pruning trees
Antiseptis treatment
Anti- termite treatment
Other__

Q.21 If there is any long- term cooperated carpenters when conducted maintenance?

☐ Yes ☐ No

■ Occurrence and treatment of termite- damage or decay

	Damaged	Not damaged	Maintenance is necessary	Unknown
Roof				
Outer wall				
Interior wall				
Basis				
Foundation				
Columns				
Beam				

	Considering maintenance	Overall maintenance	Partial maintenance
Roof			
Outer wall			
Interior wall			
Basis			
Foundation			
Columns			
Beam			

■ Disaster experience of house

Q.22 Experience of disasters and treatment

	Damaged	Not damaged	Maintenance is necessary	Unknown
Roof				
Outer wall				
Interior wall				
Basis				
Foundation				
Columns				
Beam				

	Considering maintenance	Overall maintenance	Partial maintenance
Roof			
Outer wall			
Interior wall			
Basis			
Foundation			
Columns			
Beam			

Q.23 Type of experienced disasters

☐ Earthquake ☐ Typhoon ☐ Sediment disaster ☐ Flood

☐ Tsunami ☐ High tide ☐ Fire ☐ Other__ Detail ()

Q.24 Worried disasters

☐ Earthquake ☐ Typhoon ☐ Sediment disaster ☐ Flood

☐ Tsunami ☐ High tide ☐ Fire ☐ Other__ Detail ()

Q.25 Countermeasures and preparedness against earthquake

☐ Seismic retrofit ☐ Fastening of furniture ☐ Participation of disaster drills

☐ Confirmation of shelter ☐ Confirmation of emergency contact with family members

☐ Subscription of earthquake insurance ☐ Nothing in particular ☐ Other__

Q.26 Reasons for noting conduct seismic retrofit

☐ No problems with the house ☐ Too expensive ☐ Do not own the house ☐ Hesitate to disturb neighbors ☐ Not sure whether offspring will live in the house in future

■ Perception of Nankai and Tonankai earthquakes

Q.27 Estimated time of Nankai and Tonankai earthquakes

☐ -10 yr. ☐ 10-20 yr. ☐ 20-30 yr. ☐ 30-50 yr. ☐ >50 yr. ☐ unknown

Q.28 What concerns most Nankai and Tonankai earthquakes

☐ Ground motion ☐ Tsunami ☐ Fire ☐ Other__

Q.29 Estimated results from ground motion of Nankai and Tonankai earthquakes

☐ No damage ☐ Slight damage, continue to live in ☐ Continue to live in if being repaired

☐ Reconstruction to avoid collapsing

☐ Being totally destroyed, will not live in ☐ Unknown

Q.30 Other thoughts and opinions

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Chapter 5 Application to regional seismic risk management

5.1 Introduction

The districts of groups of traditional buildings are extensively existing in Japan with various regional characteristics which highlight the Japanese traditional wisdom and constructing skills. As the historic value of traditional districts had been widely recognized, the category of important preservation districts of groups of traditional buildings (IPDGHB) was been introduced by the amendment of the Law for Protection of Cultural Properties of Japan in 1975.

After South Hyogo Earthquake occurred in 1995, it is said that Japan has already entered a period of frequent seismic activities. Damaging earthquakes happened almost every year, and the Great East Japan Earthquake occurred afterwards in 2011 (Fig 5.1). In addition, the outbreak of Nankai Trough Earthquake draws near, and the Inland crustal earthquakes will also take place around the time. Seismic damage seizes on the vulnerable part of the area and of the area and society severely, and the damage aspects vary by regions.



Figure 5.1 Earthquakes occurred after South Hyogo Earthquake

The number of the designated important preservation districts is increasing steadily from 8 in 1976 to 98 in 2012, with great disparities in physical status, social context, and risk levels [1]. The frequent seismic activities brought massive loss of people's lives, properties, as well as the heritage value of traditional buildings; therefore it is

essential to propose an integrated risk management plan for preservation districts, considering heritage value and risks, as well as the well-being of the inhabitants.

The method of regional structural investigation is outlined in this chapter, and its application on seismic risk management for IPDGHB is also proposed.

5.2 Regional structural investigation

It is very difficult to evaluate the structural performance of traditional buildings one by one due to the large number of buildings and the growing number of designated preservation districts. The traditional buildings reflect the social, technical, environmental context of the district, and share the same regional characteristics. We have proposed an onsite survey method of traditional districts for both structural properties of the wooden houses and social context, thus the regional structural characteristics could be summarized which can serve for the seismic risk management. Figure 2.1 has already indicated the framework and prospect of regional structural research of traditional districts [2].

Table 5.1 Content of regional structural field survey

	Approach	Item
L.3, L.4 Overall investigation	Structural properties	<ul style="list-style-type: none"> • Structural type • Material, etc
	Questionnaires	<ul style="list-style-type: none"> • Demographical information • Age, style, usage of the buildings • Structural types, material • Maintenances • Disaster experiences of the inhabitants and properties • Disaster perception of the inhabitants, etc
	Ambient vibration measurement	<ul style="list-style-type: none"> • Natural frequency of the ground
	Interviews with carpenters	<ul style="list-style-type: none"> • Structure, material of the buildings • Constructing technique, etc
L.1, L.2 Detailed investigation	Interviews with inhabitants	<ul style="list-style-type: none"> • Information of their families and houses • Change of the community • Maintenance of their houses • Disaster experiences and risk perception
	Ambient vibration measurement	<ul style="list-style-type: none"> • Natural frequency of the houses
	Deterioration investigation	<ul style="list-style-type: none"> • Decay • Termite damage • Moisture content, Young's modulus and inclination of column, etc.
	Investigation on structural properties	<ul style="list-style-type: none"> • Material and dimension of components • Joints, etc

In order to deal with a large number of buildings, the regional structural investigation on traditional districts is mainly divided into 2 parts, the overall investigation and detailed investigation. The overall investigation is conducted to grasp the status of a whole district, and the detailed investigation of some individual buildings is performed to further explore the structural properties, performance and status of inhabitants. Table 5.1 shows the items of the investigation.

5.3 Seismic risk management of IPDGHB

5.3.1 Premises

(1) High priority of human life

Though value of preservation objects is most frequently emphasized and assessed, in the life threatening condition, human life has indisputable priority in the decision making of emergency response. While efforts to preserve heritage should never be compromise of efforts to preserve human life in an urgent situation, nevertheless, heritage, heritage- as the tangible and intangible records of all past and current lives- deserves the utmost care in emergency response [3].

(2) Risk mitigation with minimum decreasing in heritage value

The main objectives of implementation of preservation of IPDGHB are for protecting the human life and maintain the heritage value of preservation districts. On the premise of grantee the security of inhabitants, the heritage value of preservation objects should be fully understood. Efforts to increase earthquake resistance must be based on adequate understanding of a buildings, its structural systems, construction materials and techniques, its evolution, history and conservation, its condition, its heritage values and its likely earthquake performance [3]. The implementation of built heritage preservation should integrate the consideration of both security and heritage value as shown in Figure, it is essential for professionals in different fields to establish common approaches and philosophies. All the interventions should have minimal impact on the property's heritage value, and make optimum use of traditional techniques and materials. Priorities of structural reinforcement are stated by Murakami as follows [4]:

- Additions using traditional techniques and traditional materials
- Additions using traditional techniques and techniques deriving from them, and traditional and modern materials.
- Additions using modern techniques and modern materials.
- Replacement using modern techniques and modern material.

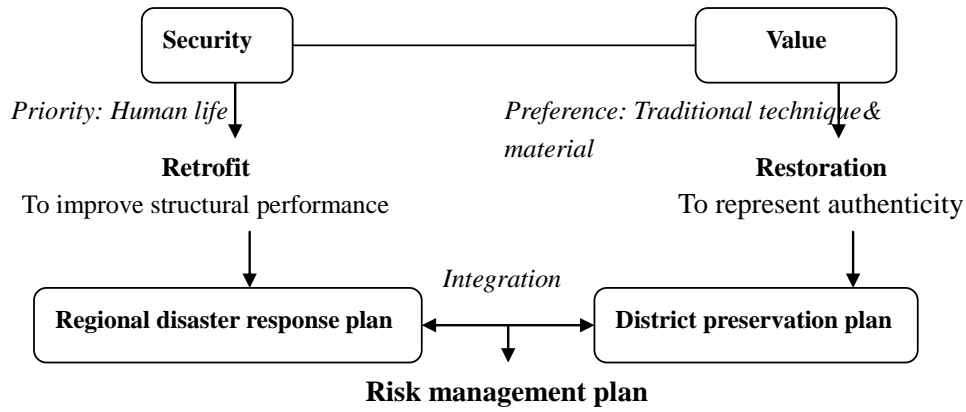


Figure 5.2 Premise: Integration of security and heritage value

5.3.2 Framework

Figure 5.3 describes the framework of seismic management of IPDGHB. To clarify the scale of application, based on the cognition of the complexity of seismic risk management of IPGHB, the managed objects are classified into 4 levels, L1: Partial, L2: Individual, L3: Collective, and L4: Regional, from micro to macro level, with the specific items are further listed in the Fig 5.4. The objective of seismic management of IPDGHB is to deal with 2 main issues, mitigation of seismic risks and preservation value of the preservation districts. The seismic risk is assessed by the hazard and the vulnerability, in this chapter, the ground motion (H1) and secondary hazards (H2) are discussed, and the factors of vulnerability are analysed from the physical (VU1) and social (VU2) aspects respectively. The process of the management is generally divided into 3 stages, S1: Identification, S2: Assessment, and S3: Intervention.

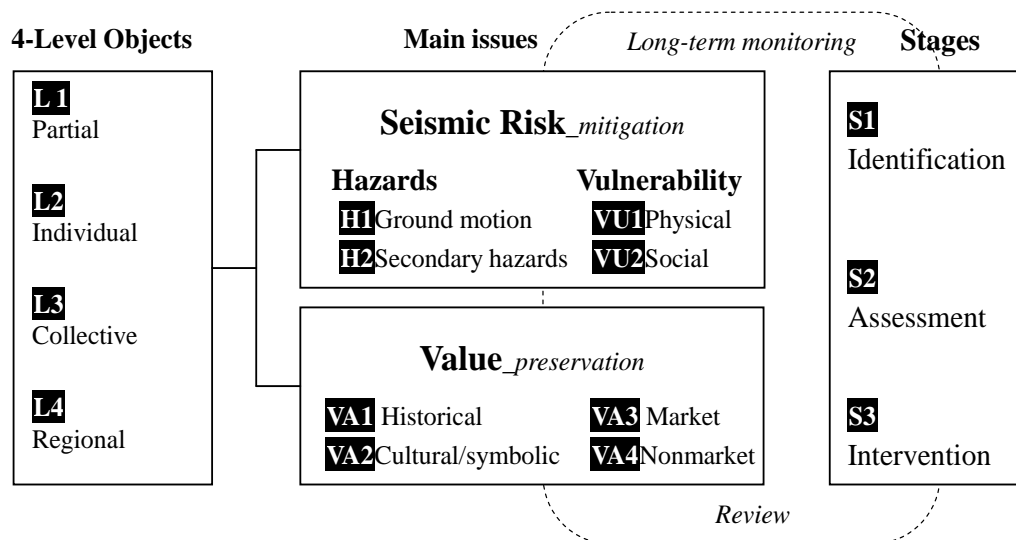


Figure 5.3 Framework of seismic risk management of IPDGHB

As shown in Figure 5.4, the objects of seismic risk management are divided into 4 levels from micro to macro, and 2 groups, the building with its surroundings and the

inhabitants. The first level (L1) includes different parts of the structures, as for the joints, columns, frame, and inhabitant as individual; the second level (L2) includes the individual building and household, the third level (L3) includes the groups of buildings and surroundings, as well as the community; the forth level (L4) includes the prototype of the architecture and the population by administrative divisions.

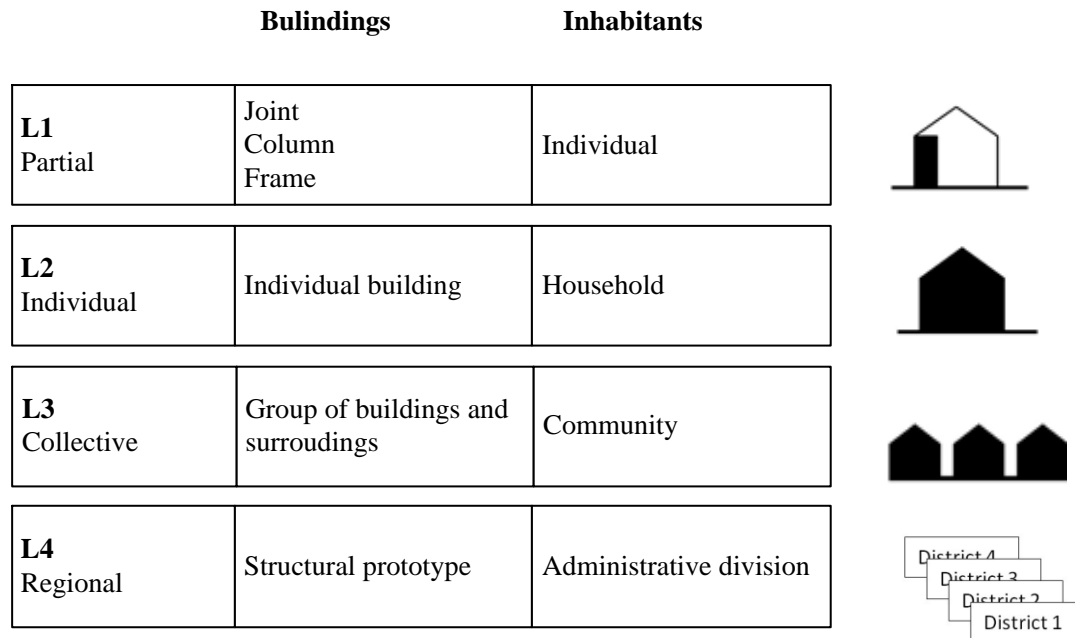


Figure 5.4 4-Level objects

Values are determining factors in preservation decision making for IPDGHB, and there are wide ranges of values which are not equally relevant to all the disciplines and stakeholders. Figure 5.5 describes Mason's typology on values of conservation, and preferences of different stakeholders and their involvement levels are indicated at the same time, though neither exhaustive nor exclusive, it offered a kind of reference for integrated risk management for IPDGHB [5].

VA1 Social-cultural value			
Historical		✓	
Cultural/Symbolic	✓	✓	✓
Social		✓	✓
Spiritual /religious			
Aesthetic		✓	✓
VA2 Economic value			
Use (market)	✓	✓	
Existence			✓
Option		✓	✓
Bequest	✓		

Based on Randall Mason cultural/ economic value typology

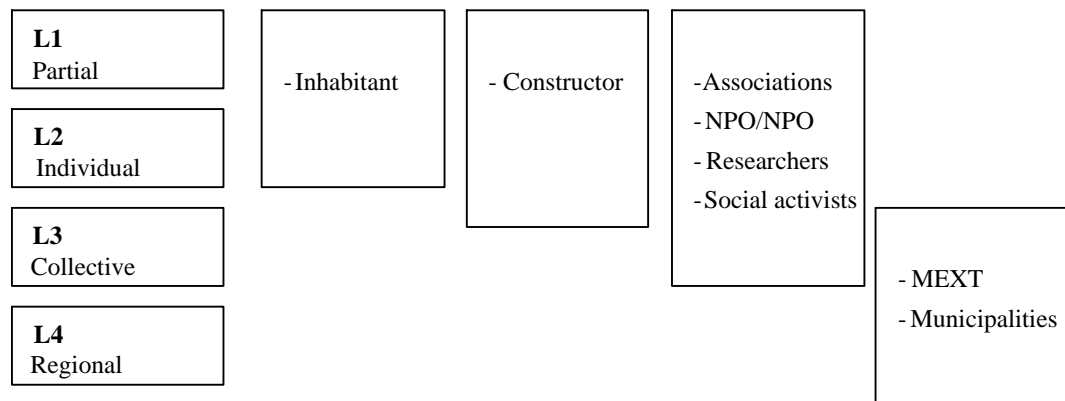


Figure 5.5 Stakeholders and value preference

5.4 Applications

5.4.1 Hazard Identification

Table 5.2 Consequences and high- risk areas

Consequences	Affected areas	Remarks
Ground motion	Inland crustal earthquake	All over Japan Pulse ground vibration
	Plate boundary earthquake	Pacific rim plain Long-term vibration
Secondary disasters	Tsunami	Coast (especially on Pacific rim) -
	Fire	City with high construction density
	Liquefaction	Reclaimed land(field, lake, coast)

There are mainly two typical earthquakes which bring hazards to the human life and property in preservation districts, the plate boundary earthquake and inland crustal earthquake. Both of the two types of earthquakes will have different influence according to the earthquake location, the recurrence interval, and scale. In addition, the secondary disasters, such as tsunami, quake, conflagration and liquefaction, caused by the earthquake, the extent of damage also vary from region to region. The affected areas and consequences are summarized in Table 5.2 [6].

To present the disaster scenario on a large scale for preservation districts in Japan, the 98 important preservation districts of groups of traditional buildings are categorized based on their history and traditional industries in Table 5.3. The number of districts with probabilities of Nankai earthquake/ tsunami and landslide of each category is also indicated in this table. Generally speaking, the mountain villages have higher risk of landslide, especially for the coastal districts along the side of Pacific Ocean on the steep terrain; they may face the double strikes from the tsunami and land slide.

Table 5.3 Classification of IPDGHB

Category	Type	Example	Number of regions	Nankai earthquake/ Tsunami	Landside
Village	Mountain village, Farming village	Muroto Kiragawa	7	1	1
Temple town	Temple town, Monks dwellings, Shake town, Temple compound town	Kashihara Imai, Kyoto Sanneizaka	7	0	1
Post town	Post town, Post-sericulture community	Shiojiri Narai, Kameyama Seki	7	0	3
Merchant quarter, Tea house town	Merchant quarter, Tea house town	Kyoto Gion Shinbashi, Mima Wagimachi& Minamimachi	23	1	2
Manufacturing town	Textile town, Wax maker quarter, Salt works town, Brewer town, Porcelain maker town	Yuasa Yuasa, Shiojiri Kisohirasawa	8	2	2
Warrior quarter	Warrior quarter, Castle town	Nichinan Obi	14	2	1
Port town	Port town, Fishing village, Boat owner's dwelling, village on island	Ine Ineura, Wajima Kuroshima	17	4	5
Mountain dwelling	Mountain dwelling, Mountain-sericulture community, Mining town	Nantan Miyama, Shiragawa Ogi	15	0	9
Total			98	10	24

Figure 5.6 shows the seismic hazard curves of 5 preservation districts (Relationship of the exceedance probability within 30 years and the maximum velocity of the ground motion on engineering bedrock), and with the same exceedance probability, the larger in maximum velocity indicates the higher degree of seismic hazard [7]. As shown in Fig.5.6, the degree of seismic hazard of Kiragawa and Yuasa, which are near the Nankai Trough, is higher than the coastal districts along the Sea of Japan, due to the coming Plate boundary earthquakes. However, a noticeable fact that many Inland crustal earthquakes happened before or after the previous Nankai and Tonankai earthquake in 1944 within short period of time, such as, 1927 North Tango earthquake, 1943 Tottori earthquake and 1948 Fukui earthquake. The Inland crustal earthquake cannot be reflected on the seismic hazards curve because of the long interval of occurrence. Though the magnitude of Inland crustal earthquake is relatively smaller, the economic loss and human suffering generated by the epicentral earthquake should not be ignored.

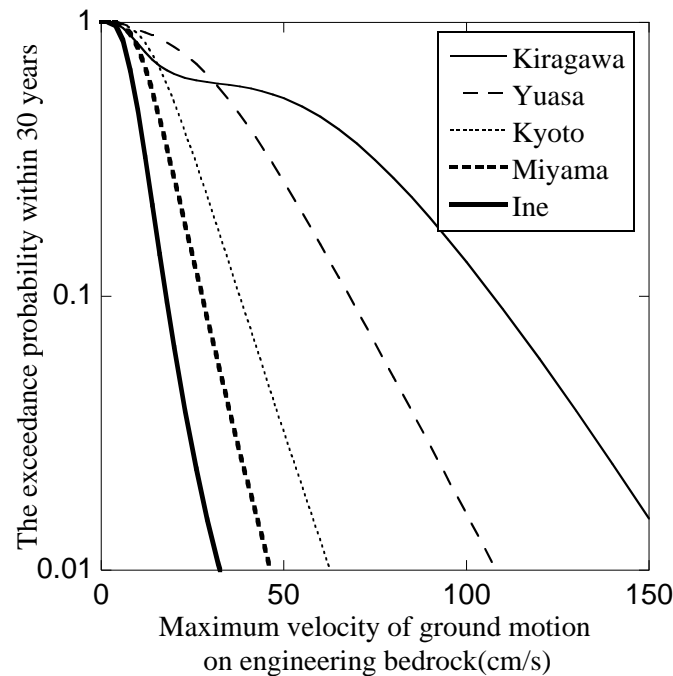


Figure 5.6 Seismic hazard curve of 5 preservation districts

Figure 5.7 (a) shows the relationship between maximum velocity of ground motion on soil surface and engineering bedrock (3% exceedance probability within 30 years) about the earthquake hazard of 98 important preservation districts and the disparities among the districts can be easily observed [8]. Moreover, Figure 5.7 (b) shows the relationship between the maximum velocity of ground motion and tsunami wave height class of the districts near Nankai Trough, while Figure 5.8 shows the earthquake hazard with the size of the diameter of a circle as the maximum speed of the soil surface (3% exceedance probability within 30 years) with different colors as the tsunami height of largest classes. According to two figures, we can get that the height of tsunami strike to the important preservation districts near Nankai Trough is very high based on the

assumed maximum velocity of ground motion. Namely, preparedness for tsunami and strong ground motion, as well as the complex disasters of liquefaction and landslide generated by the strong ground motion is needed.

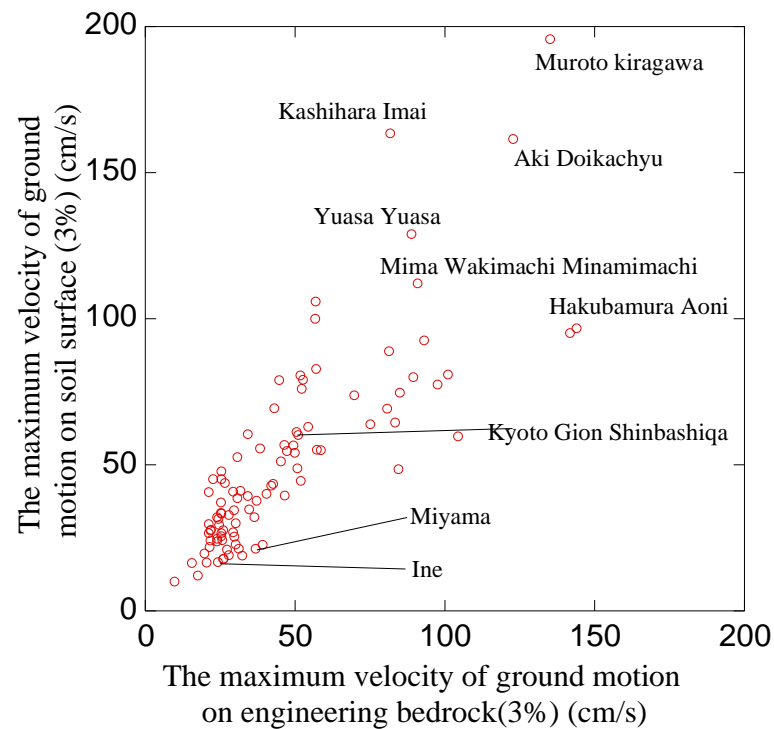


Figure 5.7 (a) Relationship between maximum velocity of ground motion on soil surface and engineering bedrock

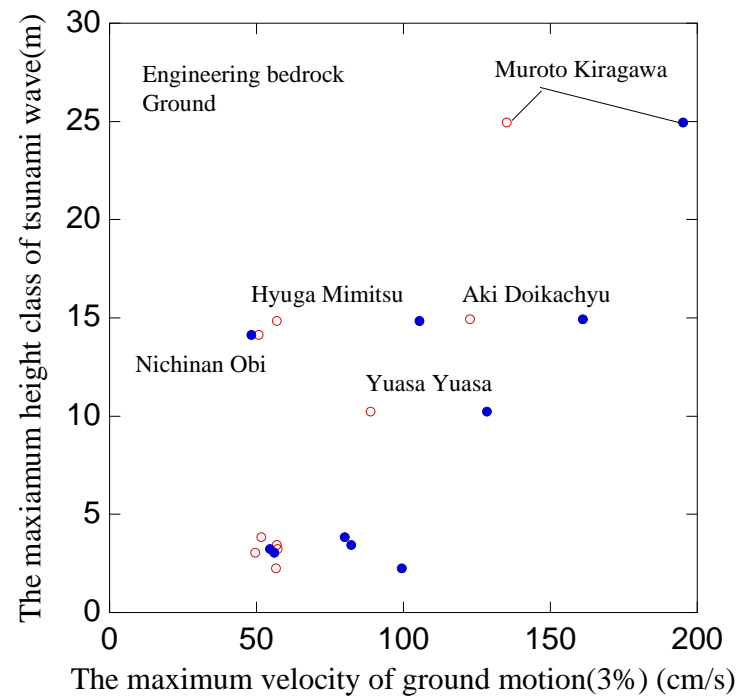


Figure 5.7 (b) Relationship between the maximum velocity of ground motion and tsunami wave height class

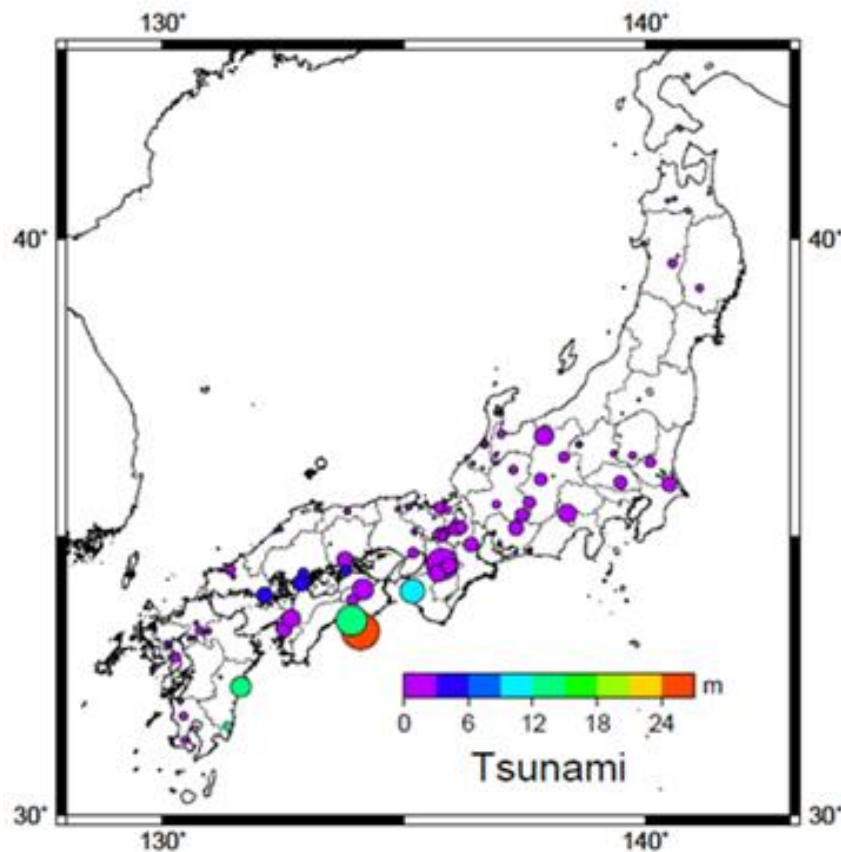


Figure 5.8 The maximum height of Tsunami in 98 districts

5.4.2 Factors of seismic vulnerability of preservation districts

There are many factors relating to the vulnerability of preservation districts, these mutual effected factors could be both physical and social as shown in Table 5.4 [9-13]. The physical status of built environment greatly affects the district vulnerability, in terms of the geographical location, distribution, scale, density of constructions, etc. Figure 5.9 shows the location of 5 preservation districts on the hazard probability map. As for the vulnerability of individual buildings, the structural characteristics and seismic performance vary in the districts, as shown in Fig 5.10, which indicates the proof stress (yield base shear coefficient) distribution by districts. In addition the efficiency of evacuation routes and disaster prevention facilities also affect the district vulnerability, and interact with the status of buildings; some buildings may collapse, during the ground motion and block the evacuation routes, and great loss may occur in that situation.

Some social factors also affect the district vulnerability, Take Fig 5.7 for instance, there is a population estimation for 5 important preservation districts from 2005 to its 30 years later [14], with population proportion of 2005 (population decline) shown as Figure 5.11 (a), and elderly (65 yrs. and older) proportion as Fig 5.11(b). Compared with 2005, in 2035, it can be approximately calculated that the depopulation percentage is large which is shown as below: 90% in Kyoto, 50% in Ine-cho and 40% in Muroto city, Kochi Prefecture (Kiragawa town). What's worse, the proportion of elderly people

in Ine-cho and Muroto city even would reach 50%. The degree of depopulation and the aging can be imagined, as what is described above that the extremely strong ground motion and high tsunami may occur in Muroto, the seismic risk is especially high in this area, and the concern about the damage of enormous materials and human beings is needed.

Table 5.4 Factors of Seismic vulnerability of preservation districts

UV1 Physical	Built environment	Buildings	Mutual house density, scale, distribution, seismic performance of building structure
		Infrastructures	Efficiency of evacuation routes, and disaster prevention facilities
	Natural environment	Geographical location	Distance to disaster resources or other underlying negative impacts
		Weather	Temperature, humidity, rain fall, etc.
UV2 Social	Demographic	Scale of population, proportion of aged people, demographic transition	
	Economic	Development of industries, ratio of employment	
	Administrative	Disaster response plan, disaster prevention drill, etc	
	Attitudinal	Willingness of preparedness, disaster consciousness, etc.	

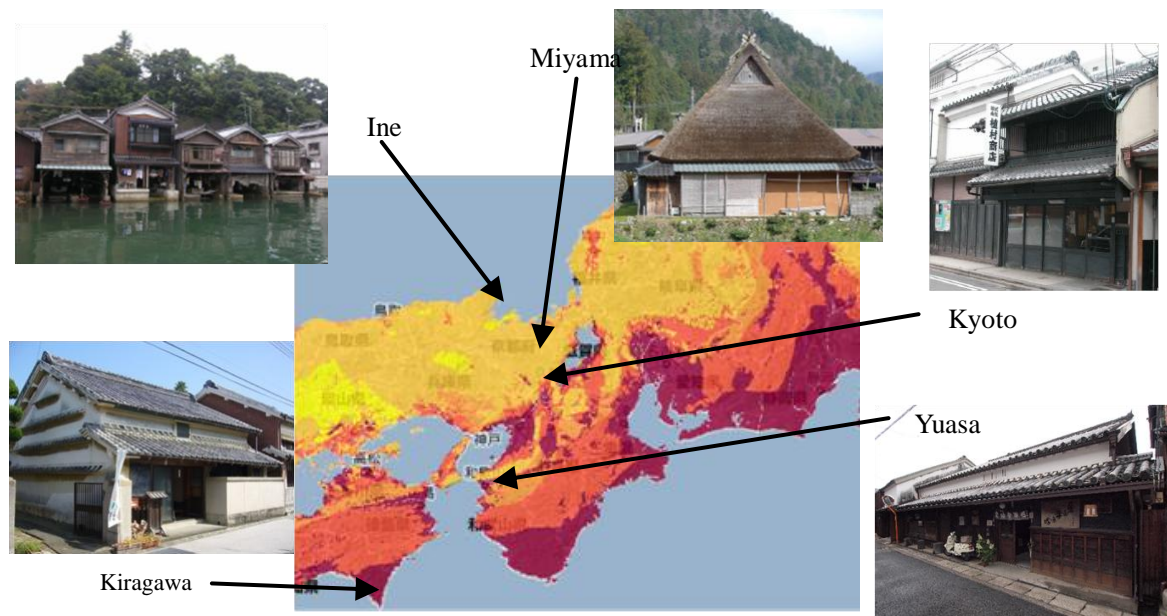


Figure 5.9 Location and typical architecture in 5 districts

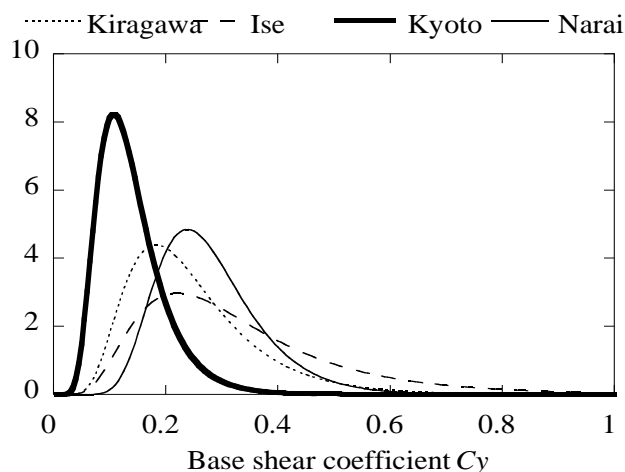


Figure 5.10 Proof stress distribution of the wooden house by districts [14]

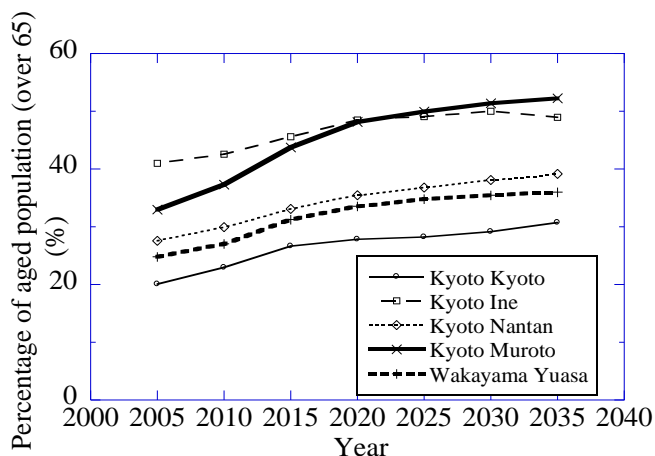
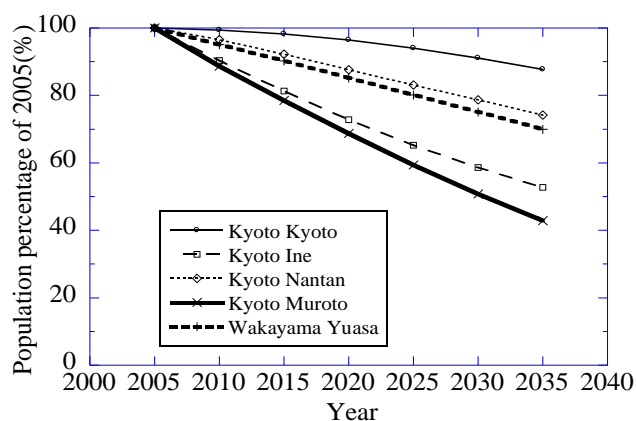


Fig.5.11 Trends of population of 5 districts

5.4.3 Interventions

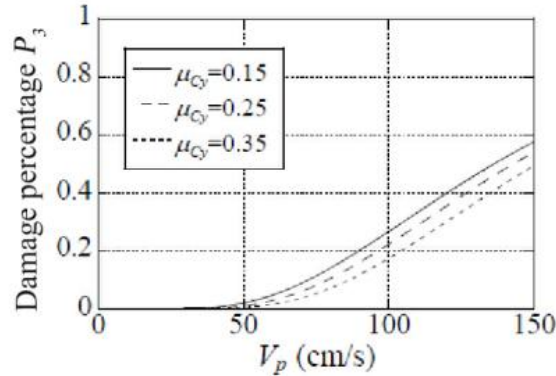
The regional structural investigation includes the comprehensive inspection on disaster risk, regional structural characteristic and seismic performance, and social context which can provide several efficient approaches to decision making in different aspects of seismic risk management for IPDGHB. The interventions for the

preservation districts to mitigate the seismic risks are proposed according the object-level, the analysis of hazards and vulnerability. The application of intervention needs to take the time, place and occasion into consideration. In order to transform the research and assessment results to concrete action, some conclusions of the regional structural research are applied in the following scenarios as examples.

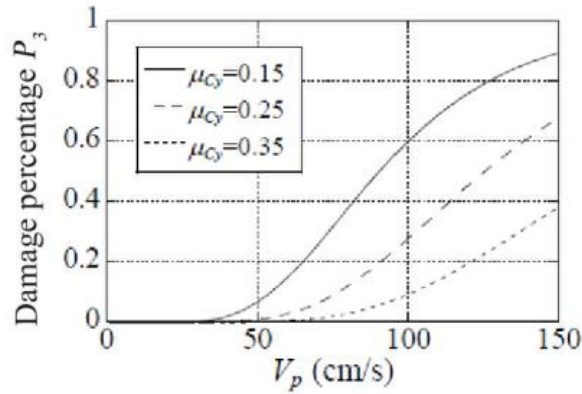
Based on the analyzed consequences, characteristics of hazards, including two typical earthquakes, and secondary disasters, different measures are required. For example, in the eastern Japan earthquake, common liquefaction and ceiling fall did not cause many building structurally to be damaged heavily. In order to reduce damage, measure implementations are not difficult, but buildings that measures haven't been taken to protect may be damaged quite possibly. For the plate boundary type earthquake, the key of implementation is to select vulnerable high buildings efficiently and to implement measures steadily within a large number of buildings. Conversely, for Inland crustal earthquake, large structural damage to buildings can be prospected, so seismic retrofitting measures to minimize structural damage come to the first and they are more desirable than those against liquefaction and ceiling fall. As to it, in the case of high risk of tsunami and tomographic misalignment, it may not be reasonable of keeping the wooden houses with the minor damage. For the quake damage, it can be better to keep no hindrance to emergency evacuation and no road block due to the dead and injury the collapsed. Therefore in the regions of high risk of tsunami with serious problems of depopulation, aging and economic downturn, threatens to large number of human lives, regional survival and living space keeping should be judged [15].

Table 5.5 Interventions by levels

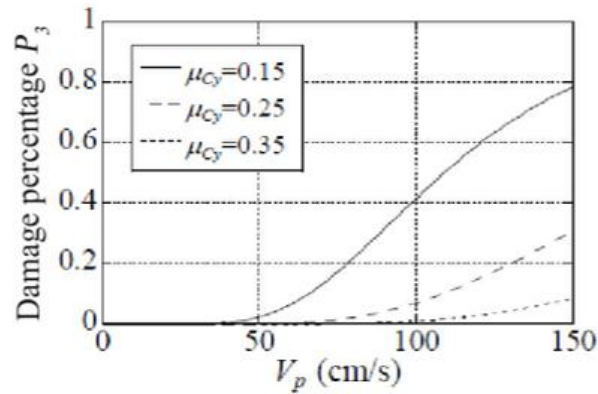
Level	S3: Intervention	
	<i>Hard</i>	<i>Soft</i>
L1 Partial	<ul style="list-style-type: none"> • Repair • Reducing ignition and bio-degradation resources • Seismic retrofit 	<ul style="list-style-type: none"> • Disaster prevention drills • Emergency supplies reserve
L2 Individual	<ul style="list-style-type: none"> • Maintenance and monitoring • Preservation plan 	<ul style="list-style-type: none"> • Insurance
L3 Collective	<ul style="list-style-type: none"> • Rapid screening • Reinforcement of poor seismic performance buildings • Evacuation plan 	<ul style="list-style-type: none"> • Advance warning • Creating an emergency team
L4 Regional	<ul style="list-style-type: none"> • Spatial planning 	<ul style="list-style-type: none"> • Legislation • Response plan • Social- Economic development



(a) $T_p=1.0s$



(b) $T_p=2.0s$



(c) $T_p=3.0s$

Figure 5.12 Difference in damage rate of the wooden house by pulse period of the pulse-related earthquake vibration T_p (μ_{Cy} : Mean proof stress of the wooden house)[16]

As shown in Figure 5.10, the statistics of C_y (yield base shear coefficient) of different districts can help to identify the districts with poor resistance houses. Additionally, in the case of inland pulses type of crustal earthquakes, which happen near epicenter, the characteristics of the seismic motion (pulse period T_p) can be forecasted in some degree, due to various magnitude and destructive process of epicenter [16]. As shown in Fig 5.12, there is a damage rate curve, whose mean value C_y of yield base shear coefficient (resistance) of regional existing wooden houses described as parameters [10]. That the

building damage mitigation may not be expected even the yield strength of houses rises, according to pulse period T_p , should be paid attention to. Damper installation may also be valid to response reduction for the long-period ground motion. However, since buildings would have been deformed more quickly than the speed of damper to absorb vibration energy, its validity may quite be limited for frequency of pulses motion. In a word, it is a necessary to forecast the characteristics of ground motion regionally, which can facilitate the estimation of damage and proposing the countermeasures.

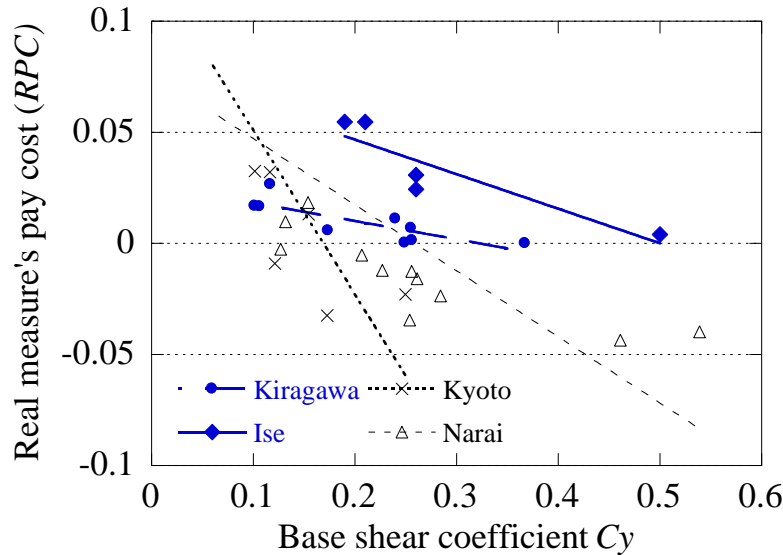


Figure 5.13 Regional comparison of the relationship between the proof stress and the earthquake loss reduction expectation by districts[17]

Taking the preparedness measures may reduce the burden on just after or post-earthquake, and are most valid as countermeasure timing. However, some investment may be fruitless as a result. For instance, Figure 5.13 shows the total damage reduction expectation value of (RPC) when a seismic retrofit has been made to existing wooden houses of the base shear coefficient C_y [17]. When $RPC > 0$, it is possible for total cost to be down can be possible. In Kiragawa and Ise that are near Nankai Trough, which are of high earthquake hazard, total cost is likely to be cut for most of the houses, while in Kyoto, which has less earthquake hazard, it is only limited to the small yield base shear coefficient with a long period of use. In other words, investment optimization to proactive measures by considering regional characteristics is needed. On the other hand, it's necessary to design the earthquake countermeasures dividing into the short-term, medium-term and long-term, from the relation to the urgency degree of earthquake occurrence and reproduction period considering the priorities and the direction. But, implementing the measures is not enough. We also need constantly monitoring the degree of disaster vulnerability and reviewing the measures.

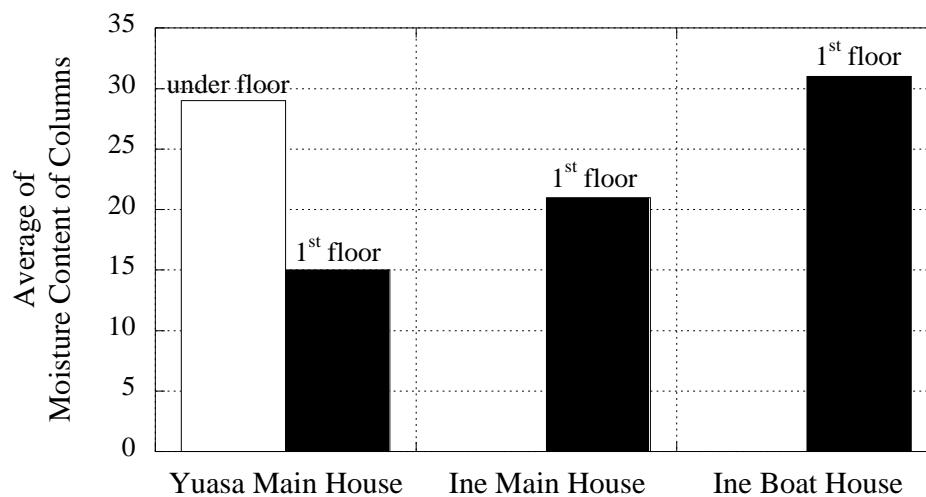


Figure 5.14 Average moisture content of houses in Ine and Yuasa

The inspection on deterioration status can help make a decision on maintenance of houses. However, it cannot be definitely said that all old wooden houses are of low seismic performance, the seismic performance of new ones also will decline over time due to the biological degradation (fungus, termite attacks, etc) [11]. Funguses start to feeds on wood when the wood members are prolonged exposure to moisture, and are most active when moisture content of wood is between 30%-60%. Figure 5.14 indicates the average moisture content of column in main houses and boat houses in Ine, as well as under floor and 1st floor of houses in Yuasa. Both the moisture content of column under floor in Yuasa and boat house in Ine and 1st floor in Ine boat house is very high, approximately 30%, and more ventilations are strongly recommended for these houses.

By analyzing the social factors related to district vulnerability, some issues related to long- term disaster prevention plan are discussed [18]. Figure 5.15 indicates the large proportion of aged people in several questionnaire survey districts, and Figure 5.16 shows the low ratio of preservation plan, with the obstacles which are indicated in Fig 5.17. As for the districts with high risk of earthquake and tsunami, and serious problems of depopulation, aging and economic downturn, where a large number of human lives are threatened, questions like whether these districts should continue to be living space, or whether some long- term fundamental districts revalidation plan could be adopted and raised.

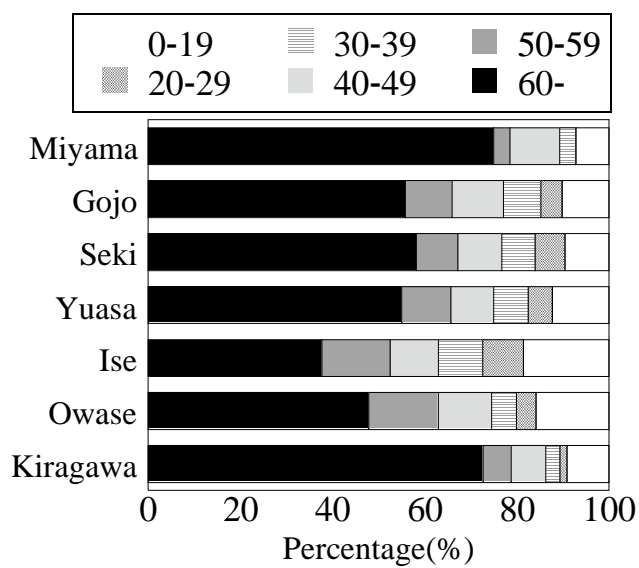


Figure 5.15 Age distribution by regions

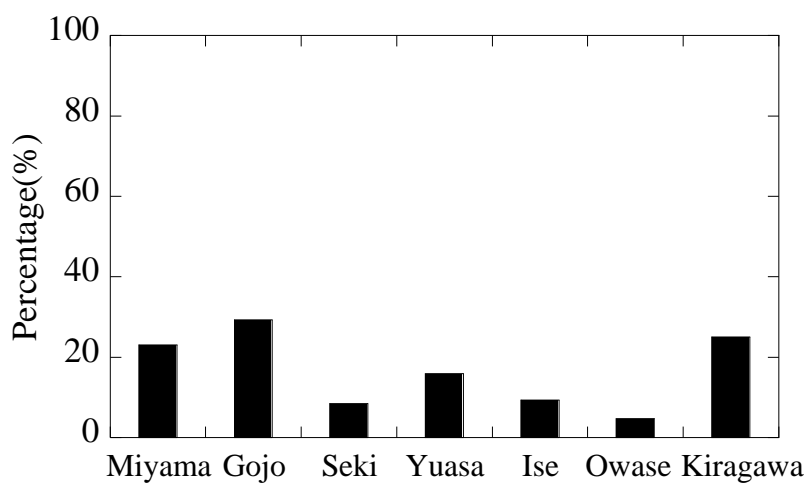


Figure 5.16 Houses with preservation plan

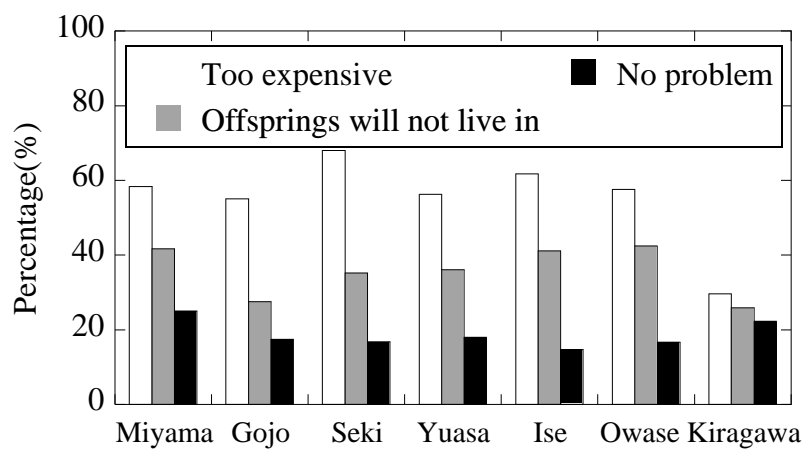


Figure 5.17 Obstacles of conducting preservation

5.5 Conclusion

Most of fatalities come from the collapse of old wooden houses according to the recent earthquake damage statistics in Japan. Therefore, it is very important to conduct seismic retrofit for old wooden houses. However, the seismic hazard, the structural characteristics of traditional wooden houses and daily problems are different from region to region. Major achievements are described as following:

- (1) Considering the heritage nature of the preservation districts, we identify the premises of seismic risk management, the priority of the security and value.
- (2) The integrated framework of regional seismic risk management is proposed, and preservation objects are classified into 4 levels, and main objectives and stages of management are identified.
- (3) We described the current conditions of seismic hazard, the consequences of ground motion and secondary disasters. The 98 designated preservation districts are classified according to the history and traditional industries, the number of districts which may be affected by earthquake/tsunami and landslide are indicated. Factors related with district vulnerability are discussed from social aspects and physical perspectives.
- (4) The interventions for the preservation districts to mitigate the seismic risks are proposed according the object-level, the analysis of hazards and vulnerability. The application of intervention needs to take the time, place and occasion into consideration.

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Chapter 6 Conclusion and future work

6.1 Conclusion

Districts of groups of traditional buildings are extensively existing in Japan with various regional characteristics which highlight the Japanese traditional wisdom and constructing skills. As the historic value of traditional districts had been widely recognized, the category of important preservation districts of groups of traditional buildings (IPDGHB) was introduced by the amendment of the Law for Protection of Cultural Properties of Japan in 1975. Important Preservation Districts for Groups of Traditional Buildings are designated according to one of three criteria: a) Groups of traditional buildings that show excellent design as a whole; b) Groups of traditional buildings and land distribution that preserve the old state of affairs well; c) Groups of traditional buildings and their surrounding environment that show remarkable regional characteristics. By far the number of the designated districts has increased to 98.

Though the social- cultural value of traditional districts have been intensively investigated and manifested through conventional district investigations, the investigation of traditional districts on physical- environmental dimension is still insufficient. The records of the earthquakes indicate that Japan has already entered the period of high- frequency seismic activities and according to the damage statistics of Japan, most of fatalities due to the structural failure of old wooden buildings. Thus it is important to estimate the seismic performance of the buildings as well as the interests of conducting seismic retrofit for the houses of the house- owners. This dissertation provides quantitative information on regional structural investigation on traditional districts. Major efforts were exerted onto the following aspects:

- (1) Method of regional structural investigation on IPDGHB: Method of overall investigation (Regional structural characteristics investigation, Ambient vibration measurement of the ground, Interview with the carpenters, Questionnaire survey) and detailed investigation (Interview with the inhabitants, Ambient vibration measurement of the houses and deterioration inspection of the houses); and results of investigation on Yuasa and Ine.
- (2) Improved stress wave velocity measurement Three Young's modulus test methods (Tapping-Tone Technique, Fakopp test and bending test); the relationship between density and Young's modulus, improved system of Fakopp; uniform direction and revise formula; demonstration under existing wooden houses, and proposed 2 methods for estimation of bending strength of column.
- (3) Questionnaire survey Questionnaire survey on habitation and disaster perception on six traditional districts: Method of questionnaire survey; seismic risk; results of questionnaire survey and discussion.
- (4) Application to regional seismic risk management: premises of seismic risk management

of IPDGHB, framework of management, 4-level objects, value preferences, hazards and vulnerability identification, and interventions.

The dissertation consists of six chapters. Chapter 1 is Introduction, including the background and objectives of the dissertation. In Chapter 2, the content of regional structural investigation is explained, and the process and results of investigation in Ine and Yuasa are used to exemplify the investigation method. Chapter 3 and Chapter 4, further interpret the details of two approaches of investigation, the improved stress wave velocity measurement and questionnaire survey. Chapter 5 discusses the preservation proposal for the traditional districts to be against the coming Nankai and Tonankai earthquakes. Major findings are summarized as follows.

a) Method of regional structural investigation on IPDGHB

Method of structural investigation on IPDGHB is introduced in this paper as a supplementary approach which can be combined with conventional district investigation methods to establish integrated evaluation system of traditional districts considering both values and risks.

Two coastal preservation districts Ine and Yuasa are investigated and compared. Regional structural characteristics and district vulnerability are different from region to region and should be taken as important indices during decision making of districts preservation.

- (1) Both of the Ine and Yuasa are confronting the issues as depopulation and aging of population, and recession of primary and secondary industries. Problems are more severe in Ine.
- (2) Seismic risk is higher in Yuasa, while the preparedness is not enough.
- (3) Comparing the structural characteristics of traditional buildings in 2 districts, though there is no significant difference of the values of W/A_1 and H , some differences can be observed as follows:
 - The dimension of column is usually $120\text{mm} \times 120\text{mm}$ in Yuasa, while the dimension of column is usually $135\text{mm} \times 135\text{mm}$ in Ine.
 - Although the seismic hazard is not severe in Ine, there are many houses with the yield base coefficient less than 0.2.
 - The moisture content of column under floor in Yuasa and the 1st floor of boat house in Ine is very high, namely the risk of deterioration is higher.
 - The big hanging walls and void space can be found in both of the districts, and the big hanging walls are distributed around the living room (Hiroma) as a square in Yuasa, and are distributed around the earth floored passage (Tooriniwa) as cross in Ine. The horizontal force could not be transferred due to the void space.

b) Improved stress wave velocity measurement

We report the progress of our research projects on improvement of Young's modulus and bending strength measuring system for existing wooden structures by one of test device, Fakopp, based on stress wave velocity. The relation of the results from some material test

methods such as Tapping-tone technique, Fakopp and bending test is studied. With improved measuring method of Young's modulus used, it can be measured precisely for existing structures. We also propose the method of determination of the timber grade of members and to verify the proposed method, and the timber grades of some columns in 6 investigated traditional districts are estimated. Finally based on the result of bending test and Fakopp test, the method of estimation of bending strength of column based on Fakopp test is proposed.

Major findings are listed as follows:

- (1) It is unreliable to apply unaided viewing inspection method in the condition of field survey on existing buildings, and improved stress wave velocity measurement is able to increase the accuracy of the estimation of the timber grade for existing buildings.
- (2) Some examination by improved stress wave measurement are conducted on cypress specimens, it is found that standard deviation under heterogeneity of density is $0.028 (t/m^3)$, and it is indicated that timber grade is estimated precise by improved method.
- (3) Based on the regression analysis of data from bending test and the improved non-destructive stress wave velocity measurement, the bending strength of column made of cedar or cypress could be estimated by the improved non-destructive stress wave velocity measurement for Young's modulus .

$$\text{a) Cedar: } F_b = 16.86 + 3.1(0.68E_f); \text{ Cypress: } F_b = 19.75 + 3.77(0.75E_f)$$

- (4) At Kyoto, Yuasa, Hashidate, Happo, Seki, and Gojo, we examined some columns of existing houses. Considering heterogeneity of density, the range of Young's modulus and grade are estimated, and the bending strength could also been indicated by the timber grade.

c) Questionnaire survey Questionnaire survey on habitation and disaster perception on six traditional districts

Since questionnaire survey is a fundamental approach to assess regional disaster vulnerability, we proposed a questionnaire survey method based on conventional questionnaire survey methods and regional built environment inspection which can efficient applied to district survey both for cultural heritage conservation and regional security management. Major conclusions are drawn as follows:

- (1) Based on the analysis of the results from questionnaire survey, all the surveyed traditional districts share many similarities: A large number of old traditional houses exist; the problem of aging population is quite obvious in all the surveyed districts and there is large number of one or two- person households consist of aged people., especially for Miyama and Kiragawa; though the ratio of the ownership of the houses is very high, people still are reluctant to conduct retrofit for their houses, mainly because of the economic pressures and problem of property inheritance; though the designation of IPDGHB brings some constraints for application of seismic retrofit, however, it does not influence the decision making of the inhabitants to do so, and there is no distinct disparities between the designated districts and un-designated districts for the reasons of reluctance of application of seismic retrofit.

- (2) The disaster countermeasures should be different according to the local disaster risks. Comparing with Kyoto, the yield base shear coefficient (C_y) of the traditional houses in surveyed districts is not low. The values of estimated PGV & tsunami height vary distinctively among the surveyed districts, and interventions for mitigation of disaster damage are proposed for each district.
- (3) Besides the seismic performance of the house, the risk perception of the inhabitants also affects the district vulnerability. As for Miyama, the ratio of inhabitants who concern earthquake is very low, because of the low seismic probability. However, the house in Miyama is very old and to prepare against the unexpected earthquake, effort on maintenance of houses is important to mitigate the deterioration of seismic performance. The ratio of inhabitants with tsunami concerns is also low in Kiragawa, because in the last Nankai earthquake the damage from tsunami was not severe. However, the value of the predicted height of tsunami wave of the coming Nankai earthquake is very large for Kiragawa, the promotion of risk awareness and disaster preparedness is highly recommended.

d) Proposal for preservation of IPDGHB considering regional characteristics

Most of fatalities come from the collapse of old wooden houses according to the recent earthquake damage statistics in Japan. Therefore, it is very important to conduct seismic retrofit for old wooden houses. However, the seismic hazard, the structural characteristics of traditional wooden houses and daily problems are different from region to region. Major achievements are described as following:

- (1) Considering the heritage nature of the preservation districts, we identify the premises of seismic risk management, the priority of the security and value.
- (2) The integrated framework of regional seismic risk management is proposed, and preservation objects are classified into 4 levels, and main objectives and stages of management are identified.
- (3) We described the current conditions of seismic hazard, the consequences of ground motion and secondary disasters. The 98 designated preservation districts are classified according to the history and traditional industries, the number of districts which may be affected by earthquake/tsunami and landslide are indicated. Factors related with district vulnerability are discussed from social aspects and physical perspectives.
- (4) The interventions for the preservation districts to mitigate the seismic risks are proposed according the object-level, the analysis of hazards and vulnerability. The application of intervention needs to take the time, place and occasion into consideration.

6.2 Future work

Though regional structural investigation method has been introduced and results of investigation of Yuasa and Ine has been provided, it could be further developed in a number of way, as for standardization of regional investigation method and further

integration with conventional method; increasing the number of surveyed districts and making the classification of regional characteristics of districts more convincing; proposing preservation/ retrofit plan for individual house in detail to integrate the results of 117 investigation with the implementation.

The effectiveness of improved non- destructive stress wave velocity testing method has been proved, and a tentative proposal for estimation of bending strength of column has also been made based on the existing data, in the future the regression analysis on the Zelkova for the bending strength estimation based on accumulation Young's modulus data by the improved testing method will be conducted, and more data will be collected for Cypress and Cedar, to improve the accuracy of the regression analysis.

The result of questionnaire survey of habitation and disaster perception has been reported and comprehensively discussed with results of regional structural research on seismic capability of house and deterioration status. The results of questionnaire survey could be further utilized for integrated disaster risk analysis for districts, and mutual effects between social indicators as for perception and behavior of residents and physical indicators as for seismic performance of structure could be further quantitatively analyzed in the future with more questionnaire surveyed data.

The integrated framework of seismic risk management of IPDGHB is proposed in the dissertation, the premises of seismic risk management have been clarified, and interventions have been proposed based on 4- level classification of preservation objects. There is a need to put framework into more concrete scenarios, to build up better reference system for decision making during the seismic risk management of IPDGHB.

6.3 Summary

In conclusion, the method of regional structural investigation on IPDGHB is introduced in this paper as a supplementary approach which can be combined with conventional district investigation methods to establish integrated evaluation system of traditional districts considering both values and risks, and results of the regional structural investigation on two districts have been further described and analyzed, the techniques of deterioration inspection and inquiring survey, and the effectiveness of these two approaches have been verified. Finally, the regional structural investigation applied to the seismic risk management for IPDGHB based on 2 premises and integrated framework.

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